Bulletin 59

DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

JOSEPH A. HOLMES, Director

INVESTIGATIONS OF DETONATORS AND ELECTRIC DETONATORS

BY

CLARENCE HALL

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SPENCER P. HOWELL

WASHINGTON
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CONTENTS.

ILLUSTRATIONS.

INVESTIGATIONS OF DETONATORS AND ELECTRIC DETONATORS.

By Clarence Hall and Spencer P. Howell.

INTRODUCTION.

Among the more important factors involved in the use of high explosives in blasting operations is the means employed to bring about the detonation of the charge. When flame is applied to high explosives many of them may burn if not confined; but all of them when burning under certain conditions of confinement may detonate. Detonation may also be effected by mechanical means, such as frictional impact caused by a blow or by rubbing between surfaces. By this means, however, the full effect of the explosive charge may not be developed, so that a partial detonation, often accompanied by the burning of the explosive, results.

When nitroglycerin was first used it was fired by the application of flame, but considerable difficulty was experienced in exploding it with certainty and in obtaining uniform results. In 1864 Alfred Noble, a Swedish engineer, discovered that nitroglycerin could be surely and completely detonated by exploding in contact with it a small quantity of an initiatory explosive. Mercury fulminate was the substance then found capable of producing the best results There are many other fulminates and other substances that will produce complete detonation of commercial "high" explosives, but detonators or electric detonators containing mercury fulminate as the characteristic ingredient are still almost exclusively used in this country.

The term "detonator" is used in the publications of the Bureau of Mines to designate what the miner calls a "blasting cap"—a copper capsule containing a small quantity of some detonating compound that is ignited by a fuse. The term "electric detonator" is applied to a blasting cap that is similar except for being ignited by means of a small wire which is heated to incandescence or fused by the passage of an electric current.

One of the conditions prescribed by the Bureau of Mines for a permissible explosive [a] is that it shall be fired by a detonator, or preferably an electric detonator, having a charge equivalent to that of the standard detonator used at the Pittsburgh testing station. A further

[a] Permissible explosives have a short, quick flame and are intended especially for use in coal mines containing inflammable gases or dusts. (See Miners' Circular 6, Bureau of Mines.)

requirement is that this charge shall consist by weight of 90 parts of mercury fulminate and 10 parts of potassium chlorate (or their equivalents).

At the request of a manufacturer of permissible explosives, an investigation was undertaken by the bureau to determine the relative strength of detonators and electric detonators having different compositions. The tests of electric detonators herein reported were conducted by H. F. Braddock, junior chemist; J. W. Koster, J. E. Tiffany, junior mining engineers; and A. S. Crossfield, junior explosives chemist, at the Pittsburgh testing station of the bureau. Similar tests of detonators were not conducted because it was believed that the results would not show sufficient variation to warrant such tests. It is hoped that the conclusions drawn from the tests made will be of service to those using explosives by enabling them to select the grade of detonator or electric detonator that will insure the most effective results. The conclusions are given in this bulletin, which is published by the Bureau of Mines as one of a series of publications dealing with the testing of explosives and the precautions that should be taken to increase safety and efficiency in the use of explosives in mining operations.

The results of the experiments described in this bulletin show that the average percentage of failures of explosives to detonate was increased more than 20 per cent when the lower grades of electric detonators were used instead of No. 6 electric detonators, and was increased more than 50 per cent when these lower grades were used instead of No. 8 electric detonators. It is noteworthy, however, that when sensitive explosives, such as 40 per cent strength ammonia dynamite (p. 33), were tested under conditions ideal for detonation, the same energy was developed irrespective of the electric detonator used. When tests were made with a less sensitive explosive, such as a 40 per cent strength ammonia dynamite containing nitrosubstitution compounds (p. 32), the energy developed increased with the grade of the electric detonator used. For example, the average efficiency of four different explosives was increased 10.4 per cent when a No. 6 electric detonator was used instead of a No. 4 electric detonator, and 14.9 per cent when a No. 8 electric detonator was used (see tabulation on p. 45). The results of the tests emphasize the importance of using explosives in a fresh condition, but as fresh explosives can not always be had in mining work, strong detonators should be used in order to offset any deterioration of explosives from age.

The results obtained substantiate the following conclusions: (1) That for any particular manufacturer's detonators or electric detonators the explosive efficiency increases with their grade, and (2) that the four No. 6 electric detonators, of different makes, tested have practically the same explosive efficiency as, and each is considered equivalent to, the Pittsburgh testing station standard No. 6 electric

detonator for use with permissible explosives in coal mines when the No. 6 grade is prescribed.

PRELIMINARY CONSIDERATIONS.

Methods for determining the strength of detonators or electric detonators by mechanical effects may be classed as either direct or indirect. The direct method comprises those tests in which the mechanical effect of the detonators or electric detonators is determined. The indirect method comprises those tests in which the mechanical effect of the explosives with which the detonators or electric detonators are used is determined. The direct method offers the advantage of simplicity, and usually of cheapness, but may lead to grave inaccuracies unless checked by mechanical effects indirectly determined. The discussion under the heading, "Tests Previously Used to Determine the Strength of Detonators" illustrates this.

The indirect method of determining the mechanical effects of explosives, or the energy developed by them, approximates practical conditions and offers an accurate means for determining the relative efficiency of detonators and electric detonators in bringing about complete detonation of commercial "high" explosives.

As all direct methods of testing detonators are therefore dependent on the indirect method for verification, the first experiments undertaken were to determine the relative strength of electric detonators indirectly by comparing the energy developed by different commercial explosives when fired with different grades of electric detonators. Afterwards tests were made by determining the relative strength of electric detonators by direct means, and a test was devised that, although not entirely satisfactory, gave results that approximated more closely those established by the indirect tests.

Detonating explosives develop their energy in the most efficient way when fired with detonators or electric detonators that completely detonate or explode them. Obviously, if the detonation be incomplete, a part of the potential energy of the explosive will not be released, and the loss of energy will be proportional to the percentage of the charge that did not detonate. In blasting operations an incomplete detonation is not only a menace to safety, by reason of the possible explosion of the unexploded part of the charge and of the harmful gaseous products resulting from the blast, but in many cases it acts like an underloaded shot and performs little, if any, useful work.

If an explosive is in a fresh condition and is sensitive to detonation and no obstacles are present to hinder its detonation, then any detonator effective enough to cause its complete detonation will develop its full energy.

In practice, however, conditions ideal for detonation rarely and perhaps never exist, because the commercial explosives are somewhat insensitive to detonation or because they may have deteriorated by

aging before use. Furthermore, crimped paper ends of the cartridges, loose material in the drill hole, air spaces between the cartridges, or cartridges of too small diameter may hinder detonation.

An explosive is said to age when any physical or chemical change during storage affects its sensitiveness, its uniformity, or its stability. Such changes are usually caused by the temperature and the humidity of the air or by sunlight, and even gravity may have an important effect. If the explosive is placed in the sunlight, it may become unstable. If a cartridge of dynamite is subjected to a temperature above 90° F., gravity may cause the segregation of nitroglycerin in the lower end or side of the cartridge. If nitroglycerin explosives are subjected to temperatures alternately above and below 52° F., the nitroglycerin tends to segregate in the cartridge. These conditions affect the uniformity of the explosives. If explosives, especially those containing ammonium nitrate or other hygroscopic salts, are subjected to a moist atmosphere they tend to absorb moisture. If the temperature is less than 52° F., nitroglycerin explosives other than low-freezing ones may freeze, and low-freezing explosives will freeze at a temperature less than 35° F. Recently, there have been placed on the market nitroglycerin explosives, styled nonfreezing explosives, that are declared by the manufacturers to remain unfrozen when the temperature falls as low as 0° F. Both moisture and freezing affect the sensitiveness of explosives.

The results of preliminary tests indicated that it would be impossible to discriminate between commercial electric detonators by determining the energy developed by explosives used with them unless the explosives were insensitive to detonation or tested under conditions which would simulate their use under actual mining conditions; consequently the authors, in testing electric detonators indirectly, used explosives in an insensitive condition. This was done by using those that were naturally insensitive, such as an explosive of class 1,[a] subclass *b;* by using explosives in cartridges having small diameters, such as the 20 per cent "straight" nitroglycerin dynamite in cartridges of ⅞-inch diameter; in an aged condition, such as the 35 per cent strength gelatin dynamite two years old; in a frozen condition, such as 40 per cent strength gelatin dynamite; and, in the case of ammonia dynamite, by the addition of water.

The apparatus used in the experimental study were the Mettegang recorder, small lead blocks, and Trauzl lead blocks. The results of the tests differentiated the electric detonators in two ways. In the first place the electric detonator either did or did not cause the detonation of the explosives. In tabulating such results the number of detonations is expressed as the percentage of the number of trials. Only the tests of those explosives were considered in which at least one failure to detonate occurred and in which detonation occurred in

[a] For an explanation of classification see p. 12.

at least one trial. In the second place, those trials in which detonation occurred were used as a basis of comparing the relative explosive efficiency of the electric detonators. The results of only those tests in which each of the electric detonators of the series caused detonation were recorded. The results are expressed in percentages of explosive efficiency as compared with the Pittsburgh testing station standard No. 6 electric detonator. This electric detonator offered the advantage of being included in both groups tested—the Pittsburgh testing station standard and the four No. 6 electric detonators.

THEORY OF DETONATION.

A short discussion of the theory of detonation as presented by Berthelot[a] is necessary in order that a better interpretation of the experiments herein reported can be made. The theory is called the "explosive-wave" theory, and it has been generally accepted because all detonation phenomena can be best explained by it. In order to analyze the propagation of an explosive wave, the wave is considered as a recurring cycle of released and transformed energy with four phases, as follows: Mechanical to calorific, calorific to chemical (the phase in which the potential energy of the explosive material is released), chemical to calorific, and calorific to mechanical.

This cycle can best be readily understood by indicating how the explosive wave is propagated through a cylindrical file of a homogeneous explosive without the loss of enough energy to interrupt propagation.

1. *Transformation of mechanical energy to calorific energy.*—When an explosive detonates a part of the mechanical energy of a layer of the explosive is converted instantly into heat energy in the adjacent layer by reason of the impact of molecules. The efficiency of this conversion is low—certainly less than 50 per cent—as the movement of the molecules is radial and they are only partly confined by the layer of explosive in the file. The mechanical energy that is not converted into heat energy exerts pressure on the confining medium and thus becomes the vehicle through which work is accomplished. There is good reason for believing that the thickness of the layer of explosive that enters into the first phase of the cycle varies with the physical properties of the explosive material, principally with its elasticity and partly with the velocity of the molecules that are in molecular vibration. The less elastic the explosive material and the greater the velocity of the molecules the thinner the layer, and hence the more times the cycle will recur in a unit length of the explosive material.

2. *Transformation of calorific energy to chemical energy.*—Some of the calorific energy of the layer is used to overcome the chemical stability of the explosive material, which may vary widely, and thus release the potential energy of the layer; the rest of the calorific

[a] Berthelot, M., Explosives and their power, 1892, pp. 88–113.

energy is used to accelerate and reinforce the chemical action. The layer of explosive by this time is developing a tremendous kinetic energy as expressed in phase 3.

3. *Transformation of chemical energy to calorific energy.*—All commercial explosives develop heat on detonation. This phase is different from the others because each of those represents some kind of kinetic energy derived entirely from the preceding phase, and consequently no one of them can have more kinetic energy than the preceding phase is capable of transferring. The conversion in this phase is complete because all the potential energy released becomes kinetic energy, which is largely calorific energy.

4. *Transformation of calorific energy to mechanical energy.*—A simple statement of this phase is that the larger volume of gases then formed from the layer of explosives is in an extremely active state of molecular vibration and that these molecules are then manifesting their energy as mechanical energy. The efficiency of conversion of calorific energy to mechanical energy is high because the conversion is very rapid and radiation and conduction losses are correspondingly small.

DETONATION OF HIGH EXPLOSIVES.

All methods used to initiate the explosive wave, or to detonate high explosives, involve the application of heat. If heat be applied directly by means of a flame such as is produced by a fuse, squib, or electric igniter, or by a spark or an incandescent solid, and the explosive be of the first order, or directly explosive, such as mercury fulminate or iodide of nitrogen, then detonation is sure and effective. If, however, the explosive be of the second order, or indirectly explosive, such as dynamite, permissible explosives, trinitrotoluene, or guncotton, then detonation, especially complete detonation, does not usually occur; hence the direct application of heat is not a sure and effective means of producing detonation.

If heat, such as is produced by the physical resistance of the explosive to a blow or impact, be applied indirectly to high explosives, then any sufficient blow or impact will cause detonation; that is, it will initiate the four-phase energy cycle, or explosive wave.

Because the impact produced by detonators is extremely quick, and their mercury-fulminate composition has a high density and releases considerable kinetic energy, the force of the impact is instantly converted into heat which is applied to a thin layer of the explosive material, thereby overcoming the chemical stability of that layer and initiating the explosive wave. Experience and investigation has proved this means of producing the detonation of explosives, those not too insensitive, to be both sure and effective; hence one is not surprised to learn that detonators are universally used.

As the mercury-fulminate composition of detonators is an explosive of the first order it may be detonated by fire, and hence fuse may

be used in connection with them. Fuse is made of a uniform outside diameter and detonators are made of a uniform inside diameter such that the fuse fits snugly into them. In using fuse, it is cut square across and inserted into the detonator until it gently touches the fulminate mixture and then the detonator is crimped on the fuse.

Similarly a detonator may be fired by means of a small platinum wire embedded into the priming composition and brought to incandescence or fused by the passage of an electric current. (See figs. 1 and 4.) The priming composition may be simply an easily inflamed material such as loose guncotton, a match composition, an explosive of the first order such as mercury fulminate, or a mercury-fulminate composition. The priming composition is placed in the detonator directly above and in contact with the main charge. The platinum bridge is attached at each end to an insulated wire; the two wires, called the legs, pass through the plug and the filling, and are connected by leading wires to the source of the electric current. When a detonator is fitted with means of firing by an electric current it is called an electric detonator. Electric detonators are particularly adapted to shot firing in fiery mines, or to the simultaneous firing of several charges. They are also adapted to any purpose for which detonators may be used, and as their use offers a greater assurance of safety they are growing in favor.

ELECTRIC DETONATORS TESTED.

The electric detonators tested were designated as the Pittsburgh testing station standard No. 3, No. 4, No. 5, No. 6, No. 7, and No. 8, the Western Coast No. 6, the special No. 6, and the foreign No. 6. For brevity the expression Pittsburgh testing station standard is abbreviated in this paper to P. T. S. S.

The P. T. S. S. No. 3 electric detonators were made at the testing station from No. 3 detonators. A cross-sectional view of one of these electric detonators is shown in figure 1. The priming charge consisted of 0.02 gram of dry, loose guncotton directly above and in contact with the compressed charge. The sulphur plug, the insulated-wire legs, and the platinum bridge were so placed that the bridge was embedded in the loose guncotton. Then the molten sulphur was poured over the plug until the cap was filled.

As detonators in this country are made of a uniform inside diameter of 0.220 inch and electric detonators of a uniform inside diameter of 0.260 inch, the P. T. S. S. No. 3 electric detonators are smaller in diameter than all the others except the special No. 6 electric detonators which were also assembled at the Pittsburgh testing station. It was impossible to procure No. 3 electric detonators in the open market, as their manufacture has recently been discontinued.

The priming charge used in the No. 3, the No. 5, and the No. 7 electric detonators consisted of loose guncotton; that in the No. 4,

the No. 6, and the No. 8 electric detonators was commercially pure mercury fulminate.

The Western Coast No. 6 and the foreign No. 6 electric detonators were used as received. The special No. 6 electric detonator was made at the testing station in the same manner as the P. T. S. S. No. 3. The primer of the western coast No. 6 was loose guncotton; that of the foreign No. 6 was a mixture of picric acid and chlorate of potash. The foreign No. 6 was so called because the detonator was imported, but the priming charge, sulphur plug, and wires were assembled by a manufacturer in this country.

These electric detonators are representative of all the electric detonators commercially used in the United States.

The P. T. S. S. No. 4, No. 5, No. 6, No. 7, and No. 8 were used as received from the manufacturers. Because of the seemingly erratic results of tests with the P. T. S. S. No. 5 electric detonators, attention is called to the fact that they were from 3 to 3½ years old when used, and that although the sulphur plug protected the fulminating composition somewhat, they were not in first-class condition.

EXPLOSIVES USED IN THE TESTS.

The explosives used in the tests are enumerated below; they included certain permissible explosives and different grades of commercial dynamites. Explosives designated as permissible by the bureau are grouped in four classes.[a] Class 1, ammonium-nitrate explosives, includes all explosives in which the characterisitc material is ammonium nitrate. The class is divided into two subclasses: Subclass *a*, including every ammonium-nitrate explosive that contains a sensitizer that is itself an explosive, and subclass *b*, including every ammonium-nitrate explosive that contains a sensitizer that is not in itself an explosive. Class 2, hydrated explosives, includes all explosives in which salts containing water of crystallization are the characteristic materials. Class 3, organic-nitrate explosives, includes all explosives in which the characteristic material is an organic nitrate other than nitroglycerin. Class 4, nitroglycerin explosives, includes all explosives in which the characteristic material is nitroglycerin.

The permissible explosives used in the tests were as follows: Sample 1, sample 2, and sample 3 of an explosive of class 1, subclass *a;* sample 1 and sample 2 of an explosive of class 1, subclass *b;* and an explosive of class 4.

The commercial grades of dynamites used were a 20 per cent "straight" nitroglycerin dynamite; a 40 per cent strength ammonia dynamite (containing nitrosubstitution compounds); a 40 per cent strength ammonia dynamite; a 35 per cent strength gelatin dynamite (2 years old); a 35 per cent strength gelatin dynamite (3 years old); and a 40 per cent strength gelatin dynamite.

[a] See Miners' Circular 6, Bureau of Mines, 1912, p. 16.

The results of physical examination of the above-mentioned explosives were as follows:

Results of physical examination of explosives used in tests.

Class and grade of explosives.	Diameter of cartridge.	Length of cartridge.	Average weight.	Cartridges redipped.	Apparent specific gravity of cartridge by sand.	Color.	Consistence.
	In.	*In.*	*Gms.*				
Class 1, subclass *a* (sample 1).	1¼	8	160	No.	1.01	Corn	Granular and fibrous; fine; soft; dry; slightly cohesive.
Class 1, subclass *a* (sample 2).	1¼	8	174	Yes.	1.09	do	Do.
Class 1, subclass *a* (sample 3).	1½	8	227	Yes.	.93	Mauve	Powdered; very fine; soft; dry; not cohesive.
Class 1, subclass *b* (sample 1).	1¾	8	277	Yes.	.88	Corn	Powdered; very fine; very dry; very soft; not cohesive.
Class 1, subclass *b* (sample 2).	1¾	8	278	Yes.	.88	do	Do.
Class 4	1¼	8	166	No.	1.00	do	Granular and fibrous; soft; fine; dry; slightly cohesive.
20 per cent "straight" nitroglycerin dynamite.	⅞	8	103	No.	1.18	do	Do,
40 per cent strength ammonia dynamite (containing nitrosubstitution compounds).	1¼	7⅞	226	Yes.	1.34	do	Fibrous; very fine; dry; soft; slightly cohesive.
40 per cent strength ammonia dynamite.	1¼	8	241	Yes.	1.43	Drab	Granular; fine; dry; soft; slightly cohesive.
35 per cent strength gelatin dynamite (2 years old).	1¼	7⅞	265	No.	1.63	Corn	Gelatinous; fine; wet; soft; moderately cohesive.
35 per cent strength gelatin dynamite (3 years old).	1⅜	7¾	339	No.	1.66	do	Do.
40 per cent strength gelatin dynamite.	1¼	7¾	295	No.	1.60	Drab	Do.

Certain of the different explosives used in the tests were analyzed, with results as follows:

Results of analyses of certain explosives used in tests.

Constituent.	Kind of explosives.					
	20 per cent "straight" nitroglycerin dynamite.[a]	40 per cent strength ammonia dynamite (containing nitrosubstitution compounds).[b]	40 per cent strength ammonia dynamite.[a]	35 per cent strength gelatin dynamite (3 years old).[b]	35 per cent strength gelatin dynamite (3 years old).[b]	40 per cent strength gelatin dynamite.[a]
Moisture	1.20	1.93	0.88	1.89	5.86	1.47
Nitroglycerin	19.54	16.28	21.60	29.03	28.10	30.70
Nitrololuene		4.97				
Nitrocellulose				.88	1.17	.88
Sodium nitrate	[c] 62.09	47.14	46.04	48.62	52.20	54.27
Ammonium nitrate		18.78	18.86			
Wood pulp	15.22		5.45		5.55	8.58
Wood pulp and crude fiber		2.84		2.15		
Calcium carbonate	1.95		1.44	1.13		
Zinc oxide		.62	.88		1.07	1.02
Sulphur		2.84	4.85	4.83	4.58	3.08
Starch		3.79		11.47		
Vaseline		.81				
Paraffin					1.24	
Rosin					.23	
Total	100.00	100.00	100.00	100.00	100.00	100.00

[a] Analyst, W. C. Cope. [b] Analyst, A. L. Hyde, [c] Contains 1.04 per cent sodium chloride.

TESTS PREVIOUSLY USED TO DETERMINE STRENGTH OF DETONATORS AND ELECTRIC DETONATORS.

Six principal tests have been used previously to determine the strength of detonators or electric detonators. They are as follows:

1. *Weight of charge.*—Ever since it was observed that certain explosives would not always detonate with a certain weight of charge of mercury fulminate or mercury-fulminate composition and that these same explosives would always detonate if the weight of charge in the detonator was increased, it has been customary to vary the charge in the detonators and to consider the weight of the charge to be an indication of the strength of the detonator. There are several grades of detonators, and they are designated by the charge of fulminate composition contained in them.

Bigg-Wither[a] arranged the following table, which was published in 1900:

Weight of charge in different grades of detonators.

Grade No.	Charge per detonator.	
	Grams.	Grains.
1	0.30	4.6
2	.40	6.2
3	.54	8.3
4	.65	10.0
5	.80	12.3
6	1.00	15.4
6½	1.25	19.2
7	1.50	23.1
8	2.00	30.9

It is to be noted that in 1900 there was no great variation in the composition of detonators. There is no indication that the relation between the effectiveness of the detonator and the weight of the charge was other than directly as the first-power function.

2. *Deformation or penetration of lead or iron plates.*[b]—Guttman[c] states: "One of the oldest and most frequently used tests for measuring the power of caps (used only with ordnance) consisted of exploding them on a lead or iron plate resting on a hollow iron ring and estimating their strength from the deformation or the penetration of the block. For larger detonators of between one-half gram and 1 gram charge as used for borehole shots, the plate would have to be of greater thickness."

3. *Radial lines on lead plates.*—Bigg-Wither, in the article mentioned above, describes in considerable detail tests made with different detonators. He used lead plates 3 mm. thick for detonators Nos. 1 to 3 and lead plates 5 mm. thick for detonators Nos. 4 to 8.

[a] Bigg-Wither, H., Notes on detonators: Trans. Inst. Min. Eng., vol. 21, 1900, p. 442.
[b] Munroe, C. E., Lecture on chemistry and explosives, 1888, pp. 22–23.
[c] Guttman, Oscar, Manufacture of explosives, vol. 2, 1895, p. 369.

The lead plates were supported on the edges, and the detonators were placed vertically on the centers of the plates. He further states that after the tests the plates may be taken as direct pictorial records of the efficiency of the detonators but that they do not record the report of the explosion, the recording of which is essential; that the detonating effect is not shown so much by the punctures as by the fine radiating marks upon the surface of the plates; that the fine markings show that the force of the explosion smashes the copper tubing to powder, some of which often adheres to the sides of the plates, and that when there are fine radiating lines around the center there are heavier markings outside. The difference in effect is probably due to the upper part of the fulminate not being completely detonated. The results of tests show that detonators may absorb moisture when stored and emphasize the importance of using a detonator of higher power than would be otherwise actually requisite.

It appears, then, that this test is one that might readily be used to distinguish between good and poor or defective detonators regardless of the charge that they contain, and for this purpose the test appears to have considerable merit. However, as an indication of the relative effectiveness of detonators of different grades, that is, containing different weights of charge, it appears to have little value.

4. *Photographs of flashes from electric detonators.*—De Grave[a] conceived the idea that the flash or flame of a detonator might vary with the grade of the detonator, and such was the result of tests made by him. He also showed that there was little, if any, difference whether the electric detonator was of high or low tension. The following table gives the results for low-tension detonators:

Results of photographs of flashes of low-tension detonators.

Grade No.—	Dimension of flash.
	Inches.
3	1.0 by 0.22
6	1.6 by .22
7	1.76 by .22
7	1.76 by .22
8	2.0 by .22
8	2.0 by .22

This test was rather unique, but from the results of tests reported it is evident that this test offers no advantage over that of the simple determination of the weight of charge contained within the detonator.

5. *Ability of detonator to explode similar detonators.*—This test is fully stated in a circular dated September 10, 1903, issued by the chief inspector of explosives (Great Britain) to the manufacturers

[a] Photographs of flashes of electric detonators: Trans. Inst. Min. Eng., vol. 15, 1897, p. 203.

and importers of detonators. The detonator is there defined[a] as "A capsule or case of such strength and construction and containing one or the other of the following explosives of the fulminate class in such quantities that the explosion of one capsule or case will communicate the explosion to other capsules or cases: (1) Fulminate of mercury, (2) fulminate of mercury and chlorate of potash, (3) other compositions."

It is obvious from the definition that with this test no discrimination between the detonators of different grades is possible.

6. *Effect on lead block when detonator is fired in bore hole.*—At the Massachusetts Institute of Technology in 1888–89, tests were conducted by Robert C. Williams and J. B. Seager and reported by Frederick W. Clark.[b]

Tests were made of 20 explosives, triple and quintuple detonators (caps) being used. In order that some of the effect of the detonator itself might be eliminated its effect was determined in the following way: The lead block used was a frustum of a cone 5½ inches high, 5¼ inches in diameter at the bottom, and 5 inches in diameter at the top. The axial bore was also a frustum of a cone three-fourths of an inch in diameter at the top, five-eighths of an inch in diameter at the bottom, and 2½ inches deep. In casting the blocks the lead was poured when "just barely melted"; the finished block weighed about 45 pounds. The detonator was placed in the bore hole, tamped with dry quartz sand, and fired by means of fuse. As the detonators were slightly less than one-fourth of an inch in diameter the distance between the caps and the walls of the bore hole averaged three-sixteenths of an inch. A tabulation of the results of the tests follows:

Results of firing detonators in bore holes of lead blocks.

Grade of detonator (cap).	Capacity of bore hole.		Difference.	Average.
	Before firing detonator.	After firing detonator.		
	C. c.	C. c.	C. c.	C. c.
"Eagle" triple[a]	14.3	17.0	2.7	
Do	14.3	16.3	2.0	2.3
Do	14.3	16.6	2.3	
"Eagle" quintuple[b]	14.3	17.2	2.9	3.1
Do	14.3	17.5	3.2	

[a] At that time the commercial grade name of the Pittsburgh testing station No. 3 detonator.
[b] At that time the commercial grade name of the Pittsburgh testing station No. 5 detonator.

It is evident that the method of conducting these tests was such that only a part of the energy of the detonator was represented by the expansion of the bore hole because much of the energy was

[a] Practical Coal Mining, vol. 2, 1903, p. 237.

[b] Some tests of the relative strength of nitroglycerin and other explosives: Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 515.

used to disintegrate and pulverize the sand. This was proven by tests made at the Pittsburgh testing station with electric detonators containing similar charges. A No. 3 electric detonator when fired in a cast-lead block with a bore hole of such size that the detonator would fit snugly within it produced an expansion of 5.8 c. c. A similar test with a No. 5 electric detonator gave an expansion of 9.2 c. c.

In the tests at the Massachusetts Institute of Technology, two detonators fired simultaneously within the bore hole produced considerably more than twice the expansion produced by one detonator, probably because the distance between the charge and the sides of the bore hole was less and, accordingly, the charging density was increased. The following tabulated results show this:

Results of firing simultaneously two detonators in bore hole of lead block.

Grade of detonator (cap).	Capacity of bore hole—		Difference.	Average.
	Before firing detonator.	After firing detonator.		
	C. c.	C. c.	C. c.	C. c.
"Eagle" triple	14.3	21.9	7.6	6.8
Do	14.3	20.4	6.1	
"Eagle" quintuple	14.3	20.0	9.7	9.7

Further lead-block tests were made with 13 sensitive explosives, both triple and quintuple detonators (caps) being used. The charge consisted of 6 grams of explosive, loaded and fired as previously described. The conclusion drawn was that explosives when fired with a quintuple detonator produce 9.7 per cent greater expansion than that produced with a triple detonator.

It is evident that in arriving at this conclusion the author did not take into consideration the fact that the quintuple detonator had a charge of 0.80 gram of fulminating composition, that the triple detonator had only a 0.54-gram charge, and that therefore the weight of the total charge, including the quintuple detonator, was increased 4.0 per cent over the weight of the total charge when triple detonators were used. Furthermore, the 4.0 per cent increase in weight represented principally mercury fulminate, a powerful, quick-acting explosive which, under the conditions of the tests, would exert its full effect in enlarging the bore hole. From the data presented, the results can not be properly interpreted as indicating that, with small charges (in this case 6 grams) of an explosive detonating directly under the influence of a detonator, an increase of the force of the explosive was obtained with a detonator of the higher grade.

The results of tests made at the Pittsburgh testing station with sensitive explosives do not substantiate the conclusions drawn. In order to differentiate between grades of electric detonators, it was necessary to use large quantities of insensitive explosives under conditions simulating those of actual blasting operations.

TESTS FOR DETERMINING DIRECTLY THE STRENGTH OF P. T. S. S. ELECTRIC DETONATORS.

CHARACTER OF ELECTRIC DETONATORS TESTED.

Tests for determining directly the strength of electric detonators were made with six grades of P. T. S. S. electric detonators (fig. 1).

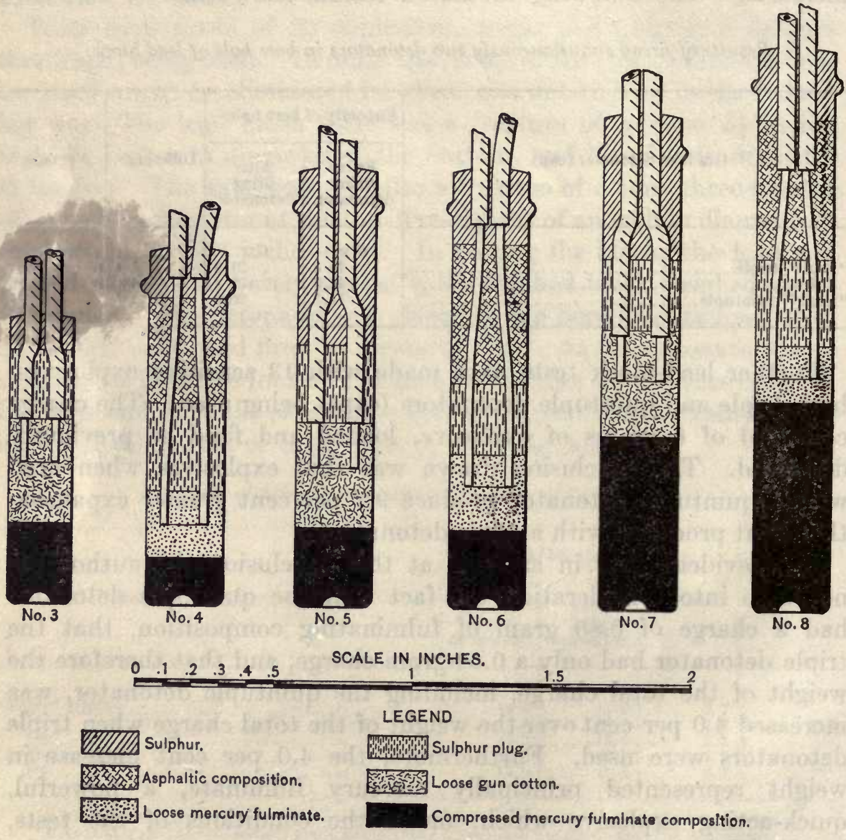


FIGURE 1.—Cross-sectional view of six P. T. S. S. electric detonators.

A physical examination of each showed the results tabulated below. Each measurement represents an average of the measurements of five electric detonators of a given grade.

Results of physical examination of P. T. S. S. electric detonators.

Grade of electric detonator.	Length of shell.	Outside diameter f shell.	Inside diameter of shell.	Thickness of shell.	Length of compressed charge.	Length of priming charge.	Length of sulphur plug.	Length of asphaltic composition, if any.	Length of sulphur filling.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
No. 3	1.00	0.234	0.220	0.007	0.28	0.37	0.25	....	0.10
No. 4	1.25	.274	.260	.007	.16	.24	.31	0.38	.16
No. 5	1.55	.274	.260	.007	.28	.37	.28	....	.62
No. 6	1.55	.274	.260	.007	.28	.27	.25	.50	.25
No. 7	1.75	.274	.260	.007	.62	.38	.25	....	.50
No. 8	2.00	.274	.260	.007	.75	.20	.31	.50	.24

Details of the wiring of the electric detonators tested are given below:

Details of the wiring of six grades of P. T. S. S. electric detonators.

Grade of electric detonator.	Distance wires projected below sulphur plug.	Distance from end of insulation to end of wires.
	Inches.	*Inches.*
No. 3	0.16	0.16
No. 4	.12	.88
No. 5	.16	.16
No. 6	.12	.94
No. 7	.19	.16
No. 8	.12	.75

The outside diameter and the thickness of the shells were determined with micrometers. The inside diameter of the shells was computed from the figures so determined. For grades Nos. 3, 5, and 7 the priming charge was guncotton. No. 3 electric detonators could not be procured from the manufacturers, so the priming charge, sulphur plug, and sulphur filling were placed in a No. 3 detonator at the Pittsburgh testing station; all other electric detonators were purchased from manufacturers.

The weights and the results of chemical analyses of the charges of the six grades of electric detonators were as follows:

Weights and results of chemical analyses of charges of P. T. S. S. electric detonators.

Grade of electric detonator.	Weight of compressed charge.	Weight of priming charge.	Weight of total charge.	Percentage in compressed charge of—		Percentage in priming charge of—		Percentage in total charge of—		
				Mercury fulminate.	Chlorate of potash.	Guncotton.	Mercury fulminate.	Mercury fulminate.	Chlorate of potash.	Guncotton.
	Grams.	*Grams.*	*Grams.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
No. 3 [a]	0.4920	0.0200	0.5120	87.94	12.06	100.00	....	84.50	11.59	3.91
No. 4 [a]	.3255	.3230	.6485	88.51	11.49	....	100.00	94.24	5.76	....
No. 5 [b]	.6990	.0240	.7230	89.13	10.87	100.00	....	86.17	10.51	3.32
No. 6 [b]	.6485	.3510	.9995	88.82	11.18	....	100.00	92.75	7.25	....
No. 7 [c]	1.4854	.0247	1.5101	88.93	11.07	100.00	....	87.47	10.89	1.64
No. 8 [d]	1.5110	.3000	1.8110	89.77	10.23	....	100.00	91.47	8.53	....

[a] Analyst, A. L. Hyde.
[b] Analyst, W. C. Cope.
[c] Analyst, C. A. Taylor.
[d] Analyst, J. H. Hunter.

7 1 5 4 8

The results of calorimeter tests are tabulated below:

Results of calorimeter tests of six grades of P. T. S. S. electric detonators.

Grade of electric detonators.	Number of electric detonators used in each test.	Number of tests averaged.	Heat evolved per electric detonator.	Total charge per electric detonator.	Heat evolved per electric detonator on the basis of a charge of 77.7 per cent mercury fulminate and 22.3 per cent chlorate of potash (exact combustion).[a]
			Large calories.	*Grams.*	*Large calories.*
No. 3	30	1	0.35	0.5120	0.36
No. 4	25	2	.48	.6485	.46
No. 5	20	2	.49	.7230	.51
No. 6	15	2	.62	.9995	.71
No. 7	10	2	1.01	1.5101	1.07
No. 8	10	2	1.14	1.8110	1.28

[a] Berthelot, M., Explosives and their power, 1892, p. 470.

The tests were made with the explosives calorimeter[a] of the Pittsburgh testing station and the rise in temperature of the water surrounding the bomb was about 0.140° C., an increase too small to insure the most accurate results. Nevertheless, the results are valuable as showing the potential energy of the electric detonators and that the potential energy is approximately a direct function of the total charge. The last column is added to show how close the heat evolved per electric detonator was to that which was to be expected had the mercury-fulminate composition been of mercury fulminate and chlorate of potash in the proportions necessary for exact combustion.

SQUIRTED LEAD BLOCK TESTS.

Tests of the six grades of electric detonators were made with squirted-lead blocks. The blocks were squirted 2 inches in diameter and were cut 3 inches long. The axial bore hole was drilled a depth equal to the length of the electric detonator to be tested and a diameter such that the electric detonator would fit snugly into it. The volume of the bore hole was measured with water before and after firing the shot. The tendency of the squirted blocks, because of their small diameter (2 inches), to bulge around the sides makes a comparison between the low-grade and the high-grade electric detonator more difficult and makes impossible a comparison of the increase in volume with the weight of total charge. Nevertheless, the volume increases with the weight of total charge as is to be expected.

[a] Hall, Clarence, Snelling, W. O., and Howell, S. P., Investigations of explosives used in coal mines; with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe: Bull. 15, Bureau of Mines, 1912, p. 109.

The results of the tests are tabulated below:

Results of tests P. T. S. S. electric detonators with squirted-lead blocks.

Grade of electric detonator.	Test No.	Volume of bore hole— Before firing detonator.	After firing detonator.	Increase of volume after firing electric detonator.	Average increase of volume.	Weight of total charge.
		C. c.	*C. c.*	*C. c.*	*C. c.*	*Grams.*
No. 3	AA47	0.9	7.5	6.6	6.4	0.5120
	AA48	.9	7.2	6.3		
No. 4	AA45	1.35	11.0	9.6	9.5	.6485
	AA46	1.35	10.8	9.4		
No. 5	AA20	1.8	13.3	11.5	11.3	.7230
	AA27	1.7	12.6	11.1		
No. 6	AA10	1.7	20.0	18.3	18.2	.9995
	AA11	1.7	19.8	18.1		
No. 7	AA18	2.1	38.5	36.4	36.7	1.5101
	AA19	1.9	38.9	37.0		
No. 8	[a] AA16	2.1	49.7	47.6	47.5	1.8110
	[a] AA17	2.15	49.6	47.45		

[a] Bottom blown out of block; it was fastened in with paraffin before volume of bore hole was measured.

CAST LEAD BLOCK TESTS.

Tests of the six grades of P. T. S. S. electric detonators were made also with cast-lead blocks. The blocks were cast as solid cylinders 100 mm. in diameter and 100 mm. high. The axial bore hole of each was drilled a depth equal to the length of the electric detonator to be tested, and of a diameter such that the electric detonator would fit snugly into it. The volume of the bore hole was measured with water before and after the shot. When more than two trials were made with any given electric detonator, the two trials that were within 5 per cent variation were selected for averaging. A comparison of the average increase of volume (y) with increase of the weight of total charge (x) shows that the relation $y=15.5\ (x=0.12)$ is closely maintained.

Plate I shows the comparative effects of the different electric detonators on the cast-lead blocks.

The details of the cast lead block tests are tabulated below:

Results of tests with cast-lead blocks of P. T. S. S. electric detonators.

Grade of electric detonator.	Test No.	Volume of bore hole— Before firing electric detonator.	After firing electric detonator.	Increase of volume.	Average increase of volume.	Weight of total charge.	Increase of volume as compared with total charge, by formula $y=15.5\ (x=0.12)$.
		C. c.	*C. c.*	*C. c.*	*C. c.*	*Grams.*	
No. 3	AA49	0.9	6.6	5.7	5.8	0.5120	6.1
	AA50	.9	6.8	5.9			
No. 4	AA51	1.35	9.3	7.95	7.8	.6485	8.2
	AA52	1.35	9.1	7.75			
No. 5	AA3	1.7	11.1	9.4	9.2	.7230	9.3
	AA39	1.7	10.7	9.0			
No. 6	AA30	1.7	16.0	14.3	14.0	.9995	13.6
	AA55	1.6	15.2	13.6			
No. 7	AA37	1.9	23.0	21.1	21.0	1.5101	21.5
	AA44	1.9	22.8	20.9			
No. 8	AA42	2.1	28.6	26.5	26.2	1.8110	26.2
	AA43	2.1	28.0	25.9			

TESTS BY EXPLOSION OF DETONATING FUSE (CORDEAU DETONANT)[a] BY INFLUENCE.

The usual method of firing detonating fuse (cordeau detonant) is to place a detonator on the end of the fuse. Some detonators will explode detonating fuse when not in direct contact with it. Hence, in the expectation that the strength of an electric detonator might be determined by varying the distance between the electric detonator and the detonating fuse, trials with a few electric detonators were made in such a way as to fix for each grade a limiting distance at which no explosion would occur, explosion occurring if the distance were lessened 1 mm.

The detonating fuse was arranged in the four different ways indicated in the following tables:

Results of explosion-by-influence tests in which detonating fuse was placed parallel with electric detonator.

Grade of electric detonator.	Test No.	Trial.	Separating distance.	Result.
			Mm.	
No. 6	M243	*a*	20	No explosion.
		b	10	Do.
		c	5	Do.
		d	0	Do.
		e	0	Do.
		f	0	Do.
		g	0	Do.
		h	0	Do.
No. 8	M245	*a*	0	Do.
		b	0	Do.
		c	0	Do.

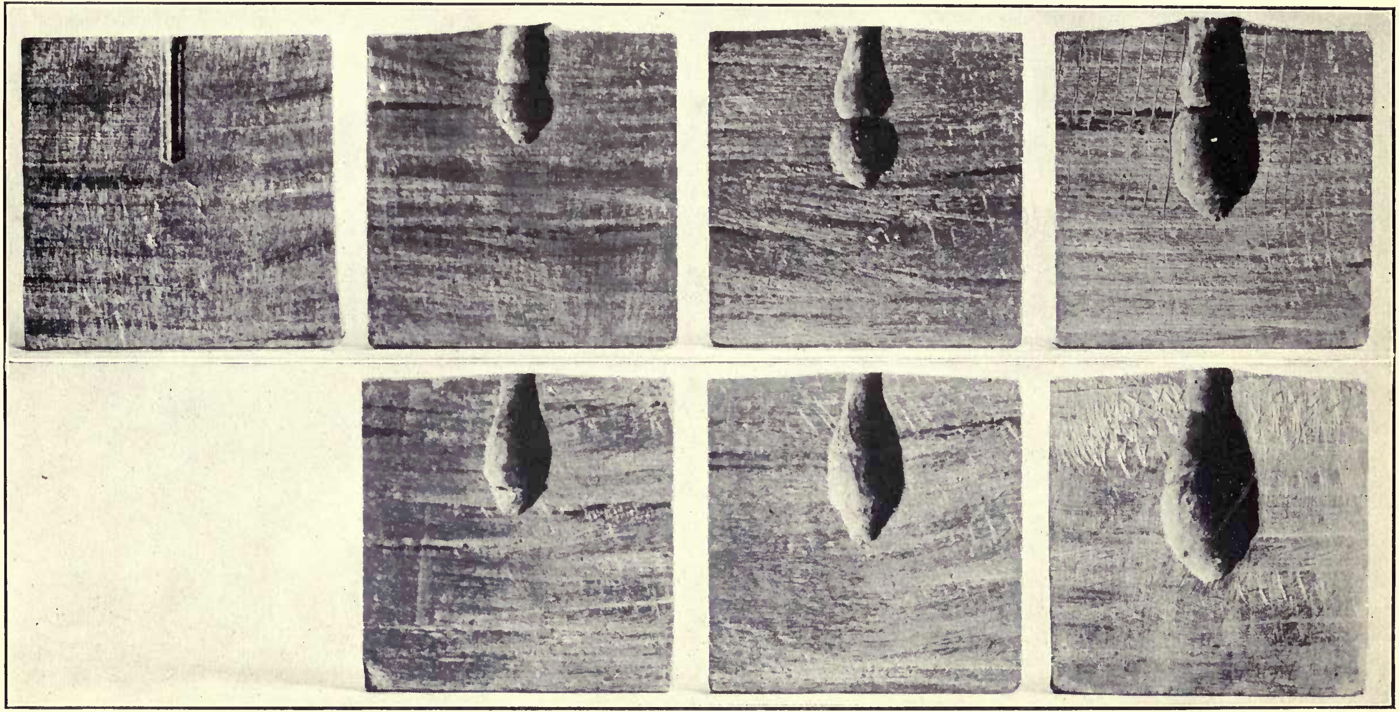
Results of explosion-by-influence tests in which side of detonating fuse touched the end of the electric detonator and was at right angles to it.

Grade of electric detonator.	Test No.	Trial.	Result.
No. 6	M244	*a*	No explosion.
		b	Do.
		c	Do.
		d	Do.
		e	Do.
No. 8	M246	*a*	Do.
		b	Do.

Results of explosion-by-influence tests in which detonating fuse and electric detonator were placed in the same axial line.

Grade of electric detonator.	Test No.	Trial.	Separating distance.	Result.
			Mm.	
No. 4	M253	*a*	5	Explosion.
		b	8	No explosion.
		c	6	Do.
		d	6	Do.
		e	6	Explosion.
		f	7	No explosion.
		g	7	Explosion.
		h	8	No explosion.
		i	8	Do.
		j	8	Do.
		k	8	Do.

[a] See p. 66.



RESULTS OF CAST LEAD BLOCK TESTS OF P. T. S. S. ELECTRIC DETONATORS. UPPER LEFT-HAND CORNER, LEAD BLOCK BEFORE TEST; LEFT TO RIGHT, BLOCKS AS AFFECTED BY DETONATORS NOS. 3, 4, 5, 6, 7, AND 8.

Results of explosion-by-influence tests in which detonating fuse and electric detonator were placed in the same axial line—Continued.

Grade of electric detonator.	Test No.	Trial.	Separating distance.	Result.
			Mm.	
No. 6	M251	*a*	3	Explosion.
		b	4	Do.
		c	5	Do.
		d	6	Do.
		e	7	No explosion.
		f	7	Do.
		g	7	Do.
		h	7	Explosion.
		i	8	Do.
		j	9	Do.
		k	10	No explosion.
		l	10	Do.
		m	10	Do.
		n	10	Do.
		o	10	Do.
No. 8	M247	*a*	0	Explosion.
		b	0	Do.
		c	10	No explosion.
		d	5	Do.
		e	1	Explosion.
		f	3	Do.
		g	4	No explosion.
		h	4	Explosion.
		i	5	No explosion.
		j	5	Do.
		k	5	Do.
		l	5	Do.

Results of explosion-by-influence tests in which detonating fuses were placed at right angles to electric detonators but at different distances from them in such a way that axial line of detonating fuse intersected side of electric detonator.

Grade of electric detonator.	Test No.	Trial.	Distance from center line of detonating fuse to end of detonator.	Separating distance.	Result.
			Mm.	*Mm.*	
No. 4	M254	*a*	5	2	No explosion.
		b	....	1	Explosion.
		c	....	2	No explosion.
		d	....	2	Do.
		e	....	2	Do.
		f	....	2	Do.
No. 6	M252	*a*	7	5	Do.
		b	....	4	Do.
		c	....	3	Do.
		d	....	2	Do.
		e	....	1	Do.
		f	....	0	Do.
		g	....	0	Explosion.
		h	....	2	No explosion.
		i	....	2	Explosion.
		j	....	3	No explosion.
		k	....	3	Do.
		l	....	3	Do.
		m	....	3	Do.
No. 8	M250	*a*	10	0	Explosion.
		b	....	4	Do.
		c	....	5	No explosion.
		d	....	5	Do.
		e	....	5	Explosion.
		f	....	6	No explosion.
		g	....	6	Do.
		h	....	6	Do.
		i	....	6	Do.
		j	....	6	Do.

The above results are so much at variance with the established explosive efficiency of detonators (see pp. 45 and 46) that this method of determining the strength of detonators is considered of little value.

The tests made with the No. 4 and the No. 6 electric detonators placed in the same axial line as that of the detonating fuse would indicate that in actual blasting there may be some advantage gained from inserting the electric detonator in the top of the primer or cartridge. Although it has been impossible to show by tests any loss in energy resulting from the detonation of an explosive when the electric detonator is placed in the side of a primer—that is, having the end of the electric detonator intersect the axial line of the primer, it is believed that the former method of insertion is preferable. When the top of the primer is opened and an electric detonator is pushed into it and the paper ends of the cartridge are gathered together and bound with twine, the electric detonator is held firmly in place. When this method is used there is less danger of the wires becoming short-circuited, and it is impossible for the end of the detonator to project through the side of the cartridge, a position that would not only tend to reduce its effectiveness, but would also be a source of danger in loading and tamping the drill hole.

TESTS BY DEPRESSION OF LEAD PLATES.

The strength of the electric detonators was also determined directly by tests involving the depression of lead plates. The details of the tests are indicated in the tabulations following:

Results of depression tests of electric detonators placed on end on ½-inch lead plates.[a]

Grade of electric detonator.	Test No.	Volume of water held in depression.[b]	Diameter of crater.	Depth of crater.	Height of cone on bottom.
		C. c.	*Mm.*	*Mm.*	*Mm.*
No. 3	M264	0.35	11	7	2
No. 4	M262	.50	13	7	4
No. 5	M157	.40	13	6	4
No. 6	M149	.40	13	7	3
No. 7	M151	.40	13	6	2
No. 8	M147	.35	13	7	2

[a] See Pl. II.

[b] The measurement of volume, which was determined with water, was unsatisfactory because of the action of surface tension, and the results are accurate only within 50 per cent. No result obtained agrees even approximately with the established results of the explosive efficiency of electric detonators (see p. 45).

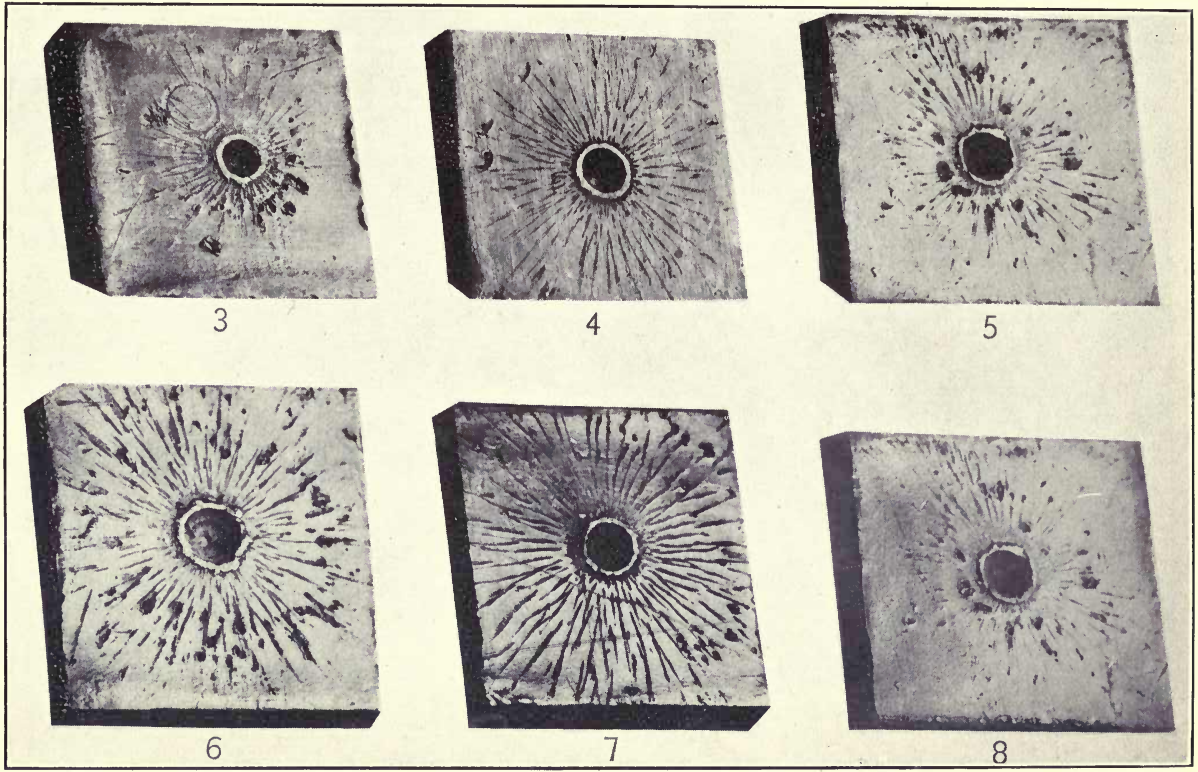
Results of depression tests of electric detonators placed on side on ½-inch lead plates.[a]

MEASURED WITH WATER.

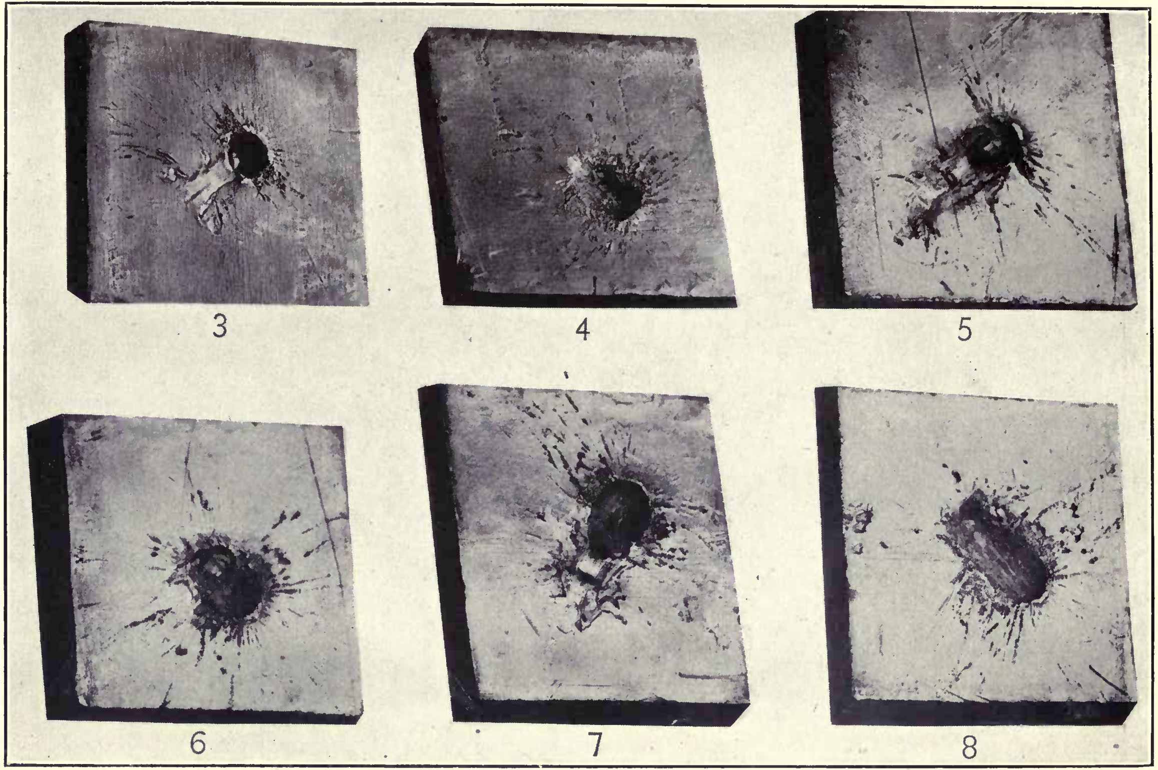
Grade of electric detonator.	Test No.	Volume.[b]	Length of crater.	Width of crater.	Depth of crater.
		C. c.	*Mm.*	*Mm.*	*Mm.*
No. 3	M265	0.30	10	10	4
No. 4	M263	.25	15	10	4
No. 5	M158	.40	15	11	4
No. 6	[c] M150	.50	21	13	5
No. 7	[c] M152	.60	20	14	5
No. 8	M148	.90	31	14	6

[a] See Pl. III. [b] See footnote of preceding table.

[c] Bottom of plate slightly raised; not raised in other tests.



SCORING OF LEAD PLATES BY P. T. S S. ELECTRIC DETONATORS NOS. 3, 4, 5, 6, 7, AND 8 PLACED ON END.



SCORING OF LEAD BLOCKS BY P. T. S. S. ELECTRIC DETONATORS NOS. 3, 4, 5, 6, 7, AND 8 LAID ON SIDE.

Results of depression tests of electric detonators placed on side on ½-inch lead plates—Con.

MEASURED WITH SAND.[a]

Grade of electric detonator.	Test No.	Plate No.	Weight of sand contained in depression No.— 1	2	3	4	5	Average of five measurements.	Grand average.	Volume.[b]
			Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*C. c.*
No. 3	M302	1	0.129	0.122	0.121	0.142	0.146	0.132		
		2	.191	.191	.194	.172	.197	.189		
		3	.226	.209	.235	.221	.229	.224	0.182	0.128
No. 4	M303	1	.379	.405	.376	.405	.365	.386		
		2	.327	.325	.333	.302	.312	.320		
		3	.415	.393	.397	.404	.386	.399	.368	.259
No. 5	M304	1	.361	.359	.340	.355	.381	.359		
		2	.382	.380	.393	.379	.390	.385		
		3	.361	.365	.377	.355	.366	.365	.370	.261
No. 6	M301	1	.574	.565	.620	.620	.590	.594		
		2	.580	.586	.607	.569	.596	.588		
		3	.622	.600	.615	.601	.598	.607	.596	.420
No. 7	M305	1	.891	.867	.890	.880	.892	.884		
		2	1.002	.994	1.034	.994	1.002	1.005		
		3	1.114	1.076	1.081	1.108	1.144	1.105	.998	.703
No. 8	M306	1	1.183	1.173	1.230	1.150	1.244	1.196		
		2	1.245	1.237	1.252	1.272	1.216	1.244		
		3	1.269	1.252	1.257	1.260	1.320	1.272	1.237	.871

[a] The sand was fine and dry.
[b] The volume was computed from the grand average weight by dividing it by the specific gravity of the sand, which was 1.42. This test was acceptable because the volume of the depression varied approximately as the explosive efficiency of the electric detonator.

THE NAIL TEST.

It was evident that the methods previously used for the direct determination of the relative strength of detonators were not satisfactory or accurate. During the latter part of the investigation an endeavor was made to devise a test that would give results approximating those obtained by the indirect tests.

In the tests made with the four No. 6 detonators having different compositions, described later, each electric detonator caused the same amount of energy to be developed from both sensitive and insensitive explosives. However, by the direct methods of testing detonators, one of the No. 6 detonators showed a much higher calorific value than any of the others, and one developed a much greater enlargement of the lead block. Nevertheless it was concluded that although the temperature developed and the volume of gases produced are functions of the efficiency of detonators, the rate of detonation or the rapidity with which the gases are developed is the prime factor and any tests that emphasized this factor should be given consideration.

The test finally decided upon is known as the nail test. This test depends on the angle formed by a nail when a detonator or electric detonator is fired in close proximity to it. For simplicity and cheapness the nail test commends itself.

Four-inch wire finishing nails (20-d.) are used in the test. For the tests herein reported the nails were selected so that they were approx-

imately of the same length, the same gage, and the same weight. The bottom of the electric detonator was placed $1\frac{3}{4}$ inches from the face of the head of the nail and was laid parallel to the nail and separated from it by two 22-gage (0.025-inch) copper wires that were wrapped around the electric detonator. The electric detonator was fastened in position by one strand of a similar copper wire, which was wrapped around it and the nail midway between the ends of the electric detonator. The whole was suspended horizontally in the air in such a manner that the nail was directly above the electric detonator, which was then fired. (Fig. 2.) The impact of the exploding electric detonator bent the nail and projected it upward. Care was taken that the nail was not hurled against any solid surface and further distorted.

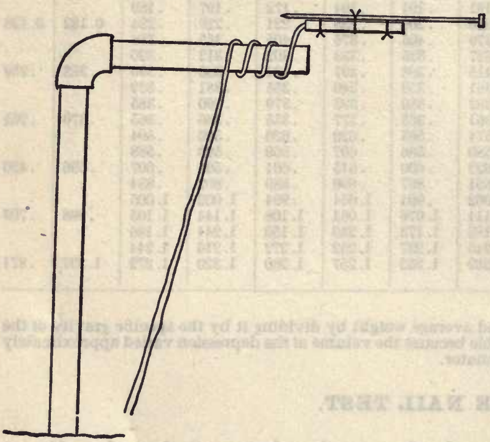


FIGURE 2.—Nail in position for test of electric detonator.

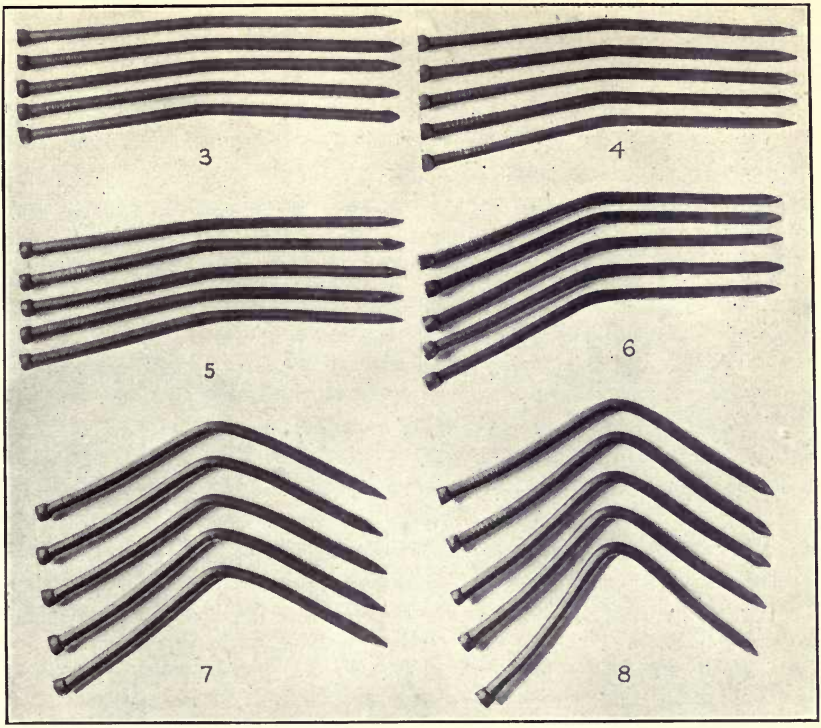
Five trials were made with each grade of electric detonator. The angle through which the nail was bent from its normal position was measured. The angle (average of five trials) was taken as a measure of the strength of the electric detonator. The results were as follows:

Results of nail tests [a] of six grades of P. T. S. S. electric detonators.

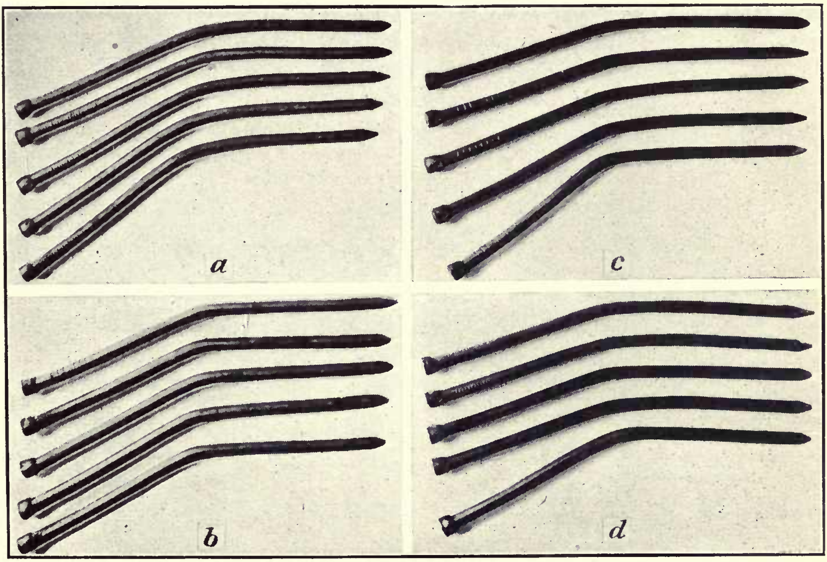
Grade of electric detonator.	Test No.	Angle of bending resulting from trial No.—					Average.
		1	2	3	4	5	
		°	°	°	°	°	°
No. 3	M279	12	10	8	9	7	9.2
No. 4	M280	12	11	14	11	16	12.8
No. 5	M281	11	13	14	13	8	11.8
No. 6	M288	23	24	25	24	26	24.4
No. 7	M283	60	50	53	54	59	55.2
No. 8	M284	68	78	76	86	98	81.2

[a] See Pl. IV, *A*.

The variation in the results of individual trials was largely due to variation in the individual electric detonators. An attempt was made to get more uniform results with annealed nails, but with these there was practically the same variation in results. In such tests, as well as in all physical tests of explosives, discrepancies resulting from unavoidable sources of error can not be eliminated, and, accordingly, only averages should be considered in comparing the practical value of the electric detonators.



A. RESULTS OF NAIL TESTS OF P. T. S. S. ELECTRIC DETONATORS NOS. 3, 4, 5, 6, 7, AND 8.



B. RESULTS OF NAIL TESTS OF NO. 6 ELECTRIC DETONATORS. *a*, WESTERN COAST; *b*, SPECIAL; *c*, P. T. S S.; *d*, FOREIGN.

TESTS FOR DETERMINING INDIRECTLY THE STRENGTH OF P. T. S. S. ELECTRIC DETONATORS.

Details of different forms of tests made to determine indirectly the strength of P. T. S. S. electric detonators are given below.

RATE-OF-DETONATION TESTS.[a]

The rate of detonation of the explosive was determined by placing the cartridges end to end in a 28-gage (B. & S.) galvanized-iron tube 42 inches long, which was of slightly larger diameter than the cartridges. The paper ends of each cartridge were cut off squarely in order that the explosive material of the cartridges would be continuous throughout the file, which was a little more than 1 meter long. Four copper wires were inserted through perforations in the tube and the cartridge file so that the distance between adjacent wires made it possible to determine the rate of detonation through the first quarter meter, the second quarter meter, the last half meter, and the entire meter, and the data were so recorded.

Each wire carried an electric current and was attached to a Mettegang recorder in such a way that at the instant the wire was broken a spark was recorded on a rapidly moving soot-covered drum. From the sparks thus recorded and the speed of the drum, the time interval between the breaking of the wires in the meter file was computed and was expressed as rate of detonation in meters per second.

The rate-of-detonation tests were carried on with different explosives as described below.

TESTS WITH AN EXPLOSIVE OF CLASS 1, SUBCLASS *a*.

In one series of tests sample 1 of an explosive of class 1, subclass *a*—an ammonium-nitrate explosive containing a sensitizer that is itself an explosive—was used. The cartridges were seven-eighths of an inch in diameter. The results were as follows:

Results of rate-of-detonation tests with sample 1 of an explosive of class 1, subclass a.

Grade of electric detonator.	Test No.	Rate of detonation in tube.							
		First quarter.		Second quarter.		Second half.		Full length.	
		Individual rate.	Average rate.	Individual rate.	Average rate.	Individual rate.	Average rate.	Individual rate.	Average rate.
		Meters per second.	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*
No. 3	M242	Detonation complete; 16 inches of explosive used.							
	M242	3 inches blown off; 16 inches of explosive used.							
	M248	Detonation complete; 16 inches of explosive used.							
No. 4	M248	Detonation complete; 16 inches of explosive used.							
	M248	Detonation complete; 16 inches of explosive used.							
No. 5	D963	2,921	....	1,956	20 inches detonated.				
	D960	2 inches blown off.							
No. 6	D966	2,445	2,458	2,678	2,632	2,205	2,205	2,368	2,362
	D967	2,472		2,586		2,205		2,356	
No. 7	D964	2,777	2,850	2,586	2,571	2,381	2,374	2,521	2,528
	D965	2,922		2,556		2,368		2,535	
No. 8	D968	2,184	2,217	2,250	2,285	2,472	2,426	2,337	2,334
	D969	2,250		2,320		2,380		2,331	
Grand average		....	2,508	....	2,496	....	2,335	....	2,408

[a] For more detailed description of this test, see Bull. 15, Bureau of Mines: Investigations of explosives used in coal mines; with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe, by Clarence Hall, W. O. Snelling, and S. P. Howell, 1912, pp. 92–95.

No detonation occurred in those tests in which 2 or 3 inches of the cartridge was blown off. In those tests in which 16 inches of the explosive was used no attempt was made to determine the rate of detonation.

The grand average indicates that the rate fell off in the last half meter. Individual tests with a given detonator showed remarkable uniformity for each electric detonator of Nos. 6, 7, and 8, and with No. 6 the maximum rate was obtained in the second quarter, with No. 7 in the first quarter, and with No. 8 in the second half. The average rates for the full length of the tube did not vary greatly.

The percentage of complete detonations with each detonator was as follows:

Percentage of complete detonations in rate-of-detonation tests with sample 1 of an explosive of class 1, subclass a.

Grade of electric detonator.	Number of tests.	Number of tests in which incomplete detonation occurred.	Complete detonations.
			Per cent.
No. 3	3	1	67
No. 4	2	0	100
No. 5	2	1	50
No. 6	2	0	100
No. 7	2	0	100
No. 8	2	0	100

These tests show that an explosive of class 1, subclass *a*, that is insensitive, tends more readily to become completely detonated with the higher grades of electric detonators, but that if the explosive detonates at all its rate is independent of the grade of electric detonator used.

The results of tests with sample 2 of an explosive of class 1, subclass *a*, follow. The cartridges used were 1¼ inches in diameter.

Results of rate-of-detonation tests with sample 2 of an explosive of class 1, subclass a.

Grade of electric detonator.	Test No.	Rate of detonation in tube. First quarter. Individual rate.	First quarter. Average rate.	Second quarter. Individual rate.	Second quarter. Average rate.	Second half. Individual rate.	Second half. Average rate.	Full length. Individual rate.	Full length. Average rate.
		Meters per second.	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*
	D1154	3,090		3,423		4,734		3,854	
	D1155	2,973		5,946		2,973		3,398	
No. 3	D1156	....	[a] 2,977	5,705	5,529	3,708	3,664	....	[a] 3,668
	D1157	2,884		7,257		3,435		3,750	
	D1158	2,960		5,488		3,516		3,673	
	D1149	3,836		4,198		3,069		3,477	
	D1150	2,973		6,286		2,933		3,398	
No. 7	D1151	2,649	3,324	5,174	4,698	3,739	3,340	3,618	3,506
	D1152	3,836		3,134		3,618		3,532	

[a] Test No. D1156 not included in average.

The averages for each detonator show a positive acceleration in the second quarter meter and a negative acceleration in the second half meter. The rates for the meter length is within the experimental error, and they were, therefore, practically uniform.

The results of tests with sample 3 of an explosive of class 1, subclass *a*, follow. The cartridges used were 1½ inches in diameter.

Results of rate-of-detonation tests with sample 3 of an explosive of class 1, subclass a.

Grade of electric detonator.	Test No.	Rate of detonation in tube.							
		First quarter.		Second quarter.		Second half.		Full length.	
		Individual rate.	Average rate.	Individual rate.	Average rate.	Individual rate.	Average rate.	Individual rate.	Average rate.
		Meters per second.	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*
No. 3	D1161	[a] 3,143							
	D1162	4,167	4,308	3,571	3,352	2,980	3,188	3,488	3,510
	D1163	4,450		3,134		3,397		3,532	
No. 7	D1127	3,477	3,451	4,045	4,170	3,450	3,327	3,589	3,518
	D1128	3,007		4,363		3,202		3,371	
	D1129	3,090		4,541		3,296		3,477	
	D1130	4,231		3,729		3,359		3,636	

[a] Detonation incomplete; test not averaged.

The average rate for the meter length was practically uniform.

The percentage of complete detonations for each electric detonator was as follows:

Percentage of complete detonations in rate-of-detonation tests with sample 3 of an explosive of class 1, subclass a.

Grade of electric detonator.	Number of tests.	Number of tests in which complete detonation occurred.	Complete detonations.
			Per cent.
No. 3	3	2	67
No. 7	4	4	100

TESTS WITH AN EXPLOSIVE OF CLASS 1, SUBCLASS *b*

The results of tests with sample 1 of an explosive of class 1, subclass *b*—an ammonium-nitrate explosive containing a sensitizer that is not in itself an explosive—follow. The diameter of the cartridges used was 1¾ inches.

Results of rate-of-detonation tests with sample 1 of an explosive of class 1, subclass b.

Grade of electric detonator.	Test No.	Remarks.
No. 3	M237	No detonation.
No. 4	M237	Do.
No. 5	D870	Do.
No. 6	D871	Do.
	D869	Do.
	D871	Do.
No. 7	D869	Do.
	D871	Do.
No. 8	D869	Do.
	D871	Do.

These tests failed to make a discrimination between the different grades of electric detonators, and hence for the purposes of this investigation were useless.

The results of tests with sample 2 of an explosive of class 1, subclass *b*, follow. The cartridges used were 1¾ inches in diameter.

Results of rate-of-detonation tests with sample 2 of an explosive of class 1, subclass b.

Grade of electric detonator.	Test No.	Rate of detonation in tube.							
		First quarter.		Second quarter.		Second half.		Full length.	
		Individual rate.	Average rate.	Individual rate.	Average rate.	Individual rate.	Average rate.	Individual rate.	Average rate.
		Meters per second.	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*
No. 3	M232	6 inches of cartridge blown off.							
	M241	4 inches of cartridge blown off.							
	M241	4 inches of cartridge blown off.							
	M240	3 inches of cartridge blown off.							
	M240	3 inches of cartridge blown off.							
No. 4	M231	6 inches of cartridge blown off.							
	M241	4 inches of cartridge blown off.							
	M241	4 inches of cartridge blown off.							
	M240	4 inches of cartridge blown off.							
	M240	4 inches of cartridge blown off.							
No. 5	M240	4 inches of cartridge blown off.							
	M241	4 inches of cartridge blown off.							
	M241	4 inches of cartridge blown off.							
	D923	4 inches of cartridge blown off.							
	D926	4 inches of cartridge blown off.							
No. 6	M249	Detonation complete; 16 inches of explosive used.							
	D930	8 inches of cartridge blown off.							
	D931	3,000	3,000	3,750	3,750	3,333	3,333	3,333	3,333
	D932	8 inches of cartridge blown off.							
	D1110	5 inches of cartridge blown off.							
No. 7	M241	Detonation complete; 16 inches of explosive used.							
	M241	Detonation complete; 16 inches of explosive used.							
	D928	3,358		3,462		3,743		3,475	
	D929	3,462	3,384	3,814	3,589	3,082	3,430	3,333	3,415
	D956	3,333		3,491		3,464		3,437	
No. 8	M241	Detonation complete; 16 inches of explosive used.							
	D925	2,647		3,214		4,286		3,462	
	D927	3,169	3,072	3,750	3,290	3,147	3,544	3,285	3,319
	D954	3,235		3,055		3,358		3,247	
	D955	3,235		3,142		3,384		3,283	
Grand average.		....	3,180	....	3,460	....	3,475	....	3,357

It is probable that no detonation occurred in those tests in which 3 to 8 inches of the cartridge was blown off. In the trial listed under test M 241 only 16 inches of explosive was used and no attempt was made to determine the rate of detonation.

The grand average shows the tendency of the rate of detonation to increase beyond the first quarter.

It is interesting to observe that the rate of detonation for that 10 centimeters of a 1¾-inch cartridge just beyond the electric detonator, as determined with the cordeau detonant, was as follows: For a No. 7 electric detonator, 3,387 meters per second; for a No. 8 electric detonator, 3,387 meters per second.

The percentage of complete detonations for each detonator was as follows:

Percentage of complete detonations in rate-of-detonation tests with sample 2 of an explosive of class 1, subclass b.

Grade of electric detonator.	Number of tests.	Number of tests in which incomplete detonation occurred.	Complete detonations.
			Per cent.
No. 3	5	5	0
No. 4	5	5	0
No. 5	5	5	0
No. 6	5	3	40
No. 7	5	0	100
No. 8	5	0	100

These tests show that an explosive of class 1, subclass *b*, that is insensitive, tends more readily to become completely detonated with the higher grades of electric detonators, but that if the explosive detonates at all its rate is independent of the grade of electric detonator used.

TESTS WITH A 20 PER CENT "STRAIGHT" NITROGLYCERIN DYNAMITE.

The results of tests with a 20 per cent "straight" nitroglycerin dynamite follow. The cartridges were seven-eighths of an inch in diameter.

Results of rate-of-detonation tests with a 20 per cent "straight" nitroglycerin dynamite.

Grade of electric detonator.	Test No.	Rate of detonation in tube. First quarter. Individual rate.	First quarter. Average rate.	Second quarter. Individual rate.	Second quarter. Average rate.	Second half. Individual rate.	Second half. Average rate.	Full length. Individual rate.	Full length. Average rate.
		Meters per second.	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*
No. 3	D1096	2,528	2,654	3,648	3,308	2,853	3,004	2,918	2,962
	D1097	2,781		2,967		3,156		3.007	
No. 4	D1098	2,418	2,600	3,423	3,195	2,834	2,852	2,834	2,852
	D1099	2,781		2,967		2,871		2,871	
No. 5	D992	3,225	2,986	2,781	2,854	2,908	2,948	2,947	2,928
	D993	2,747		2,928		2,987		2,908	
No. 6	D1000	3,729	3,838	2,683	2,563	2,767	3,038	2,933	3,046
	D1001	[a] 3,034		3,034		3,121		3,077	
	D1002	3,947		2,443		3,309		3,158	
No. 7	D1003	3,836	3,480	2,500	2,543	2,947	3,070	2,986	2,993
	D1004	3,125		2,586		3,192		3,000	
No. 8	D1005	3,358	3,310	2,679	2,728	2,980	3,010	2,980	3,000
	D1006	3,261		2,778		3,041		3,020	
Grand average.		....	3,145	....	2,865	....	2,987	....	2,964

[a] Average rate for the first half meter; rate not included in average.

In the tests where electric detonators Nos. 3, 4, and 5 were used a considerably lower rate of detonation occurred in the first quarter than in the tests where electric detonators Nos. 6, 7, and 8 were used.

Detonation was complete with every grade of electric detonator.

The figures in the grand average indicate that the rate was influenced by a negative acceleration in the second quarter meter, followed by a positive acceleration in the second half meter, though the contrary was true for electric detonators of grades Nos. 3 and 4. All tests except test D993 conformed to this.

The uniformity of the rates for the last half meter and for the meter for every grade are noteworthy; this uniformity held for individual tests as well as for averages.

TESTS WITH A 40 PER CENT STRENGTH AMMONIA DYNAMITE CONTAINING NITROSUBSTITUTION COMPOUNDS.

The results of tests with a 40 per cent strength ammonia dynamite containing nitrosubstitution compounds follow. The cartridges used were seven-eighths of an inch in diameter and had been repacked.

Results of rate-of-detonation tests with a 40 per cent strength ammonia dynamite containing nitrosubstitution compounds.

Grade of electric detonator.	Test No.	Rate of detonation in tube.							
		First quarter.		Second quarter.		Second half.		Full length.	
		Individual rate	Average rate.	Individual rate.	Average rate.	Individual rate.	Average rate.	Individual rate.	Average rate.
		Meters per second.	Meters per second.	Meters per second.	Meters per second.	Meters per second.	Meters per second.	Meters per second.	Meters per second.
No. 5	[a] D878	....	2,498	....	3,014	....	2,286	2,811	2,412
	D882	2,136		3,929		2,045		2,350	
	D903	2,679		2,586		2,284		2,446	
	D921	2,679		2,528		2,528		2,439	
No. 6	[a] D875	3,666	2,363	....	2,594	[b] 2,435	2,593	2,659	2,527
	D904	2,368		2,296		2,572		2,446	
	[a] D905	[c] 2,285		....		2,813		2,521	
	D919	2,472		3,041		2,663		2,695	
	D920	2,250		2,446		2,543		2,439	
No. 7	[a] D873	2,631	2,543	....	2,709	[b] 2,668	2,619	2,658	2,608
	D906	2,394		2,273		2,830		2,557	
	[a] D907	[c] 2,367		....		2,987		2,641	
	D918	2,616		2,961		2,528		2,647	
	D959	2,619		2,894		2,500		2,619	
No. 8	[a] D872	2,716	2,310	....	3,146	[b] 2,453	2,755	2,514	2,652
	D881	2,558		3,667		2,280		2,597	
	D910	1,542		3,209		3,345		2,561	
	D911	2,123		2,815		2,711		2,557	
	[a] D915	....		....		....		2,195	
	D916	2,679		3,041		2,744		2,795	
	D917	2,647		3,000		2,695		2,752	

[a] Rate of detonation not averaged.
[b] Rate for last three-fourths of a meter.
[c] Rate for first one-half of a meter.

No tests were made with electric detonators Nos. 3 and 4. The average rate for the meter length increased slightly with the grade of electric detonator used. The fastest rate is recorded for the second quarter meter. The figures for the average rates and for most of the individual tests indicate that the rate increased up to a maximum, and then decreased. With some electric detonators the maximum was reached in the first quarter meter, as in test D903; with others in the second quarter meter, as in test D919; and with others in the second half meter, as in test D910.

If it be assumed that the recorded rate was slightly erratic, but had a general tendency to increase to a maximum, and then to decrease toward an asymptotic normal rate, then the results of all the tests conformed to this assumption.

TESTS WITH A 40 PER CENT STRENGTH AMMONIA DYNAMITE.

The results of tests with a 40 per cent strength ammonia dynamite follow. The cartridges used were 1¼ inches in diameter.

Results of rate-of-detonation tests with a 40 per cent strength ammonia dynamite.

Grade of electric detonator.	Test No.	Rate of detonation in tube.							
		First quarter.		Second quarter.		Second half.		Full length.	
		Individual rate.	Average rate.	Individual rate.	Average rate.	Individual rate.	Average rate.	Individual rate.	Average rate.
		Meters per second.	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*
No. 3	D1139	4,018	3,954	4,412	4,532	4,545	4,242	4,369	4,223
	D1140	4,327		4,592		4,054		4,245	
	D1141	3,516		4,592		4,128		4,054	
No. 8	D1136	3,437	3,479	4,314	4,868	4,889	4,429	4,293	4,211
	D1137	3,250		5,291		4,417		4,213	
	D1138	3,750		5,000		3,982		4,128	

Only the No. 3 and the No. 8 electric detonators were used. The average rate for the meter length is practically the same for the two detonators. The rate increased to a maximum in the second half meter and then decreased as shown by averages; the results of individual tests confirm this conclusion. The rate in the last half meter corresponded closely with the average rate for the meter length.

TESTS WITH A 35 PER CENT STRENGTH GELATIN DYNAMITE 2 YEARS OLD.

The results of tests with a 35 per cent strength gelatin dynamite (2 years old) follow. The cartridges used were 1¼ inches in diameter.

Results of rate-of-detonation tests with a 35 per cent strength gelatin dynamite (2 years old).

Grade of electric detonator.	Test No.	Length of file[a] blown off or detonated.	Percentage inches that detonated.	Average percentage that detonated.	Remarks.
		Inches.	*Per cent.*	*Per cent.*	
No. 3	M231	6.5	15	15.0	Partial detonation.
No. 4	M234	7.5	18	18.5	Do.
No. 5	D887	7.0	0	....	No detonation.
	D888	7.0	0	....	Do.
	D942	13.0	31	....	Partial detonation.
	D943	13.0	31	15.5	Do.
No. 6	D889	7.0	0	....	No detonation.
	D896	18.0	43	....	Partial detonation.
	D958	17.0	40	28.0	Do.
No. 7	D890	12.0	29	....	Do.
	D895	12.0	29	....	Do.
	D957	12.0	29	29.0	Do.
No. 8	D891	18.0	43	....	Do.
	D892	12.0	29	....	Do.
	D940	15.0	36	....	Do.
	D941	14.0	33	35	Do.

[a] Full length of file, 42 inches.

The evidence of no detonation in tests D887, D888, and D889 was that nothing but the noise of the detonator was audible when the trials were made.

In tests M231 and M234 an 8-inch cartridge was used.

In no trial was more than 18 inches of the 42 inches detonated. The part that detonated, in general, varied directly with the grade of the detonator.

The number of partial detonations with each detonator was as follows:

Number of partial detonations in rate-of-detonation tests with a 35 per cent strength gelatin dynamite (2 years old).

Grade of electric detonator.	Number of tests.	Number of tests in which partial detonation occurred.	Percentage of partial detonations.
			Per cent.
No. 3	1	1	100
No. 4	2	2	100
No. 5	4	2	50
No. 6	3	2	67
No. 7	3	3	100
No. 8	4	4	100

Except with the No. 3 and the No. 4 electric detonators, the number of tests with which was small, the percentage of partial detonations increased with the grade of the electric detonator.

TESTS WITH A 40 PER CENT STRENGTH GELATIN DYNAMITE, FROZEN.

The results of tests with a 40 per cent strength gelatin dynamite (frozen) follow. The diameter of the cartridges used was 1¼ inches.

Results of rate-of-detonation tests with a 40 per cent strength gelatin dynamite (frozen).

Grade of electric detonator.	Test No.	Rate of detonation. First quarter.	Second quarter.	Second half.	Total.
		Meters per second.	*Meters per second.*	*Meters per second.*	*Meters per second.*
No. 3 [a]	D 1087	3 inches blown off.			
No. 4	D 1088	4,018	6,429	5,890	5,376
No. 5	D 1089	6,250	7,258	5,769	6,207
No. 6	D 1093	4,167	7,759	6,522	5,921
No. 7	D 1094	4,687	6,429	5,769	5,591
No. 8	D 1095	4,018	7,500	6,522	5,806
Grand average		4,628	7,075	6,094	5,780

[a] No detonation occurred with the No. 3 electric detonator.

The grand averages show that the maximum rate occurred in the second quarter, with a subsequent falling off in the rate; moreover, each individual test showed similar results, irrespective of the grade of the electric detonator used.

The variation of 14.4 per cent in the average rate is rather high, and is seemingly due to the fact that results with frozen explosives are always erratic.

Complete detonation occurred in each test with each of the six electric detonators except the No. 3, which failed to detonate.

TESTS WITH A 35 PER CENT STRENGTH GELATIN DYNAMITE 3 YEARS OLD.

The results of tests with a 35 per cent strength gelatin dynamite (three years old) follow. The cartridges used were 1½ inches in diameter.

Results of rate-of-detonation tests with 35 per cent strength gelatin dynamite (3 years old).

Grade of electric detonator.	Test No.	Remarks.
No. 3	M238	No detonation.
No. 4	M238	Do.
No. 5	D868	Do.
No. 7	D866	Do.
No. 8	D865	Do.

The explosive was so old and insensitive to detonation that for the purpose of discriminating between grades of electric detonators it was useless, because in no test did detonation occur. No tests were made with the No. 6 electric detonator.

SMALL LEAD BLOCK TESTS.[a]

The lead blocks used in the small lead block tests were squirted with a diameter of 1½ inches and were cut to a length of 2½ inches. An annealed steel disk 1½ inches in diameter and one-quarter inch high was placed above each block and above this was placed the 100-gram charge of the explosive, held in position by a paper sleeve wrapped around the block and the disk and extending above them. The electric detonator used was centrally placed in the top of the charge. When the explosion was fired, the block rested on a firm horizontal steel base. The compression of the block was determined by measuring the difference in the height of the block before and after firing.

TESTS WITH A 20 PER CENT "STRAIGHT" NITROGLYCERIN DYNAMITE WITH 6 PER CENT OF ADDED WATER.

The results of tests of a 20 per cent "straight" nitroglycerin dynamite follow. The explosive contained 6 per cent of added water:

Results of small lead block tests with a 20 per cent "straight" nitroglycerin dynamite containing 6 per cent of added water.

Grade of electric detonator.	Test No.	Compression.	Average compression.
		Mm.	*Mm.*
No. 3	B755	14.00	14.08
	B764	14.25	
	B773	14.00	
No. 4	B756	15.00	14.67
	B765	14.50	
	B774	14.50	
No. 5	B757	14.25	14.08
	B766	14.00	
	B775	14.00	
No. 6	B761	15.00	15.00
	B770	15.00	
	B779	15.00	
No. 7	B762	15.25	15.25
	B771	14.75	
	B780	15.75	
No. 8	B763	15.50	15.50
	B772	15.75	
	B781	15.25	

The No. 8 electric detonator produced a compression 9.6 per cent greater than that of the No. 3 electric detonator; in general with the explosive tested, the compression increased with the grade of the detonator. The No. 4 electric detonator, however, developed more energy than did the No. 5.

[a] For a more extended description of the small lead block test, see Bull. 15, Bureau of Mines: Investigations of explosives used in coal mines; with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Monroe, by Clarence Hall, W. O. Snelling, and S. P. Howell, 1912, pp. 113-114.

TESTS WITH A 20 PER CENT "STRAIGHT" NITROGLYCERIN DYNAMITE, FROZEN AND CONTAINING LESS THAN 6 PER CENT OF ADDED WATER.

The results of tests with a 20 per cent "straight" nitroglycerin dynamite (frozen and containing no added water or 2.5 or 4 per cent of added water) are tabulated below:

Results of small lead block tests of a 20 per cent "straight" nitroglycerin dynamite (frozen and containing less than 6 per cent of added water).

Grade of electric detonator.	Test No.	Temperature of frozen explosive.	Percentage of added water.	Compression.	Average compression.
		°C.		Mm.	Mm.
No. 3	B616	+2.0	0	14.25	13.33
	B622	−1.0	2.5	13.25	
	B647	−9.0	4.0	12.50	
No. 4	B617	+2.0	0	14.50	13.42
	B623	−1.0	2.5	13.25	
	B648	−9.0	4.0	12.50	
No. 5	B618	+2.0	0	13.50	13.00
	B624	−1.0	2.5	13.00	
	B649	−9.0	4.0	12.50	
No. 6	B619	+2.0	0	13.50	13.25
	B625	−1.0	2.5	13.25	
	B653	−9.0	4.0	13.00	
No. 7	B620	+2.0	0	15.00	13.83
	B625	−1.0	2.5	13.50	
	B654	−9.0	4.0	13.00	
No. 8	B621	+2.0	0	15.25	13.92
	B627	−1.0	2.5	13.25	
	B655	−9.0	4.0	13.25	

The tests showed the tendency of the electric detonators to increase slightly in explosive efficiency with the grade, but again the No. 3 and the No. 4 electric detonators showed an increase over the No. 5 and even over the No. 6.

TESTS WITH A 20 PER CENT "STRAIGHT" NITROGLYCERIN DYNAMITE, FROZEN AND CONTAINING 6 PER CENT OF ADDED WATER.

As no failures had occurred with any of the electric detonators, when tested with the 20 per cent "straight" nitroglycerin dynamite, a sample of that explosive with 6 per cent of added water was frozen (temperature 9° C.) and was tested, with results as follows:

Results of small lead block tests with a 20 per cent "straight" nitroglycerin dynamite (frozen and containing 6 per cent of added water).

Grade of electric detonator.	Test No.	Compression.	Average compression.
		Mm.	Mm.
No. 3	B728	[a] 0.00	0.00
	B737	[a] .00	
	B746	[a] .00	
No. 4	B729	[a] .00	.00
	B738	[a] .00	
	B747	[a] .00	

[a] Incomplete detonation.

Results of small lead block tests with a 20 per cent "straight" nitroglycerin dynamite (frozen and containing 6 per cent of added water)—Continued.

Grade of electric detonator.	Test No.	Compression.	Average compression.
		Mm.	*Mm.*
No. 5	B730 B739 B748	a 0.00 a .00 a .00	0.00
No. 6	B734 B743 B752	a .00 a .00 a .00	.00
No. 7	B735 B744 B753	12.75 13.75 a .50	9.00
No. 8	B736 B745 B754	12.75 13.75 a 1.00	9.17

a Incomplete detonation.

The number of complete detonations with each detonator was as follows:

Number of complete detonations with a 20 per cent "straight" nitroglycerin dynamite (frozen and containing 6 per cent of added water).

Grade of electric detonator.	Number of tests.	Number of tests in which complete detonation occurred.	Percentage of complete detonations.
No. 3	3	0	0
No. 4	3	C	0
No. 5	3	0	0
No. 6	3	0	0
No. 7	3	2	67
No. 8	3	2	67

The explosive was very insensitive and complete detonation occured only with the No. 7 and No. 8 electric detonators and with them in only two out of three trials with each.

TESTS WITH A 40 PER CENT STRENGTH AMMONIA DYNAMITE WITH 6 PER CENT OF ADDED WATER.

The results of tests with a 40 per cent strength ammonia dynamite with 6 per cent of added water are tabulated below:

Results of small lead block tests with a 40 per cent strength ammonia dynamite containing 6 per cent of added water.

Grade of electric detonator.	Test No.	Compression.	Average compression.
		Mm.	*Mm.*
No. 3	B656 B665 B674 B683 B692	7.25 8.50 9.50 8.25 7.75	8.25

Results of small lead block tests with a 40 per cent strength ammonia dynamite containing 6 per cent of added water—Continued.

Grade of electric detonator.	Test No.	Compression.	Average compression.
		Mm.	*Mm.*
No. 4	B657	7.25	8.20
	B666	8.75	
	B675	8.50	
	B684	8.00	
	B693	8.50	
No. 5	B658	6.00	7.70
	B667	7.25	
	B676	8.75	
	B685	8.00	
	B694	8.50	
No. 6	B662	9.75	8.95
	B671	8.75	
	B680	9.25	
	B689	7.75	
	B698	9.25	
No. 7	B663	8.00	9.15
	B672	8.75	
	B681	10.00	
	B690	10.25	
	B699	8.75	
No. 8	B664	8.75	9.70
	B673	9.50	
	B682	10.75	
	B691	9.75	
	B700	9.75	

This explosive showed a marked tendency to be erratic both with the higher and with the lower grades of electric detonators.

The explosive efficiency of the electric detonators increased with the grade of the electric detonator, except that the efficiency of the No. 5 electric detonator was considerably low and that of the No. 3 a trifle high.

TESTS WITH A 40 PER CENT STRENGTH GELATIN DYNAMITE, FROZEN.

Following are the results (Pl. V, *A*) of tests with a 40 per cent strength gelatin dynamite that was in a frozen condition:

Results of small lead block tests with a 40 per cent strength gelatin dynamite (frozen).

Grade of electric detonator.	Test No.	Temperature of frozen explosive.	Compression.	Average compression.
		°*C.*	*Mm.*	*Mm.*
No. 3	B633	−2.5	[a] 3.00	14.25
	B638	−5.0	16.75	
	B701	+0.5	13.00	
	B710	+2.5	13.50	
	B719	+2.5	13.75	
No. 4	B629	−4.5	[a] 1.50	12.62
	B639	−5.0	15.50	
	B702	+0.5	10.75	
	B711	+2.5	11.00	
	B720	+2.5	13.25	
No. 5	B630	−4.5	[a] 1.00	13.12
	B640	−5.0	17.25	
	B703	+0.5	13.75	
	B712	+2.5	10.75	
	B721	+2.5	10.75	

[a] Incomplete detonation.

Results of small lead block tests with a 40 per cent strength gelatin dynamite (frozen)—Con.

Grade of electric detonator.	Test No.	Temperature of frozen explosive.	Compression.	Average compression.
		° C.	*Mm.*	*Mm.*
No. 6	B631	−4.5	12.50	
	B644	−5.0	19.25	
	B707	+0.5	14.25	14.95
	B716	+2.5	14.25	
	B725	+2.5	14.50	
No. 7	B632	−4.5	14.50	
	B645	−5.0	20.25	
	B708	+0.5	18.00	17.00
	B717	+2.5	16.25	
	B726	+2.5	16.00	
No. 8	B637	−2.5	15.75	
	B646	−5.0	18.00	
	B709	+0.5	19.75	17.80
	B718	+2.5	17.25	
	B727	+2.5	18.25	

The results were very erratic. The strength of the detonators increased with the grade of the electric detonator used, as shown by the average compression, except that the compression with the No. 3 electric detonator was comparatively high.

The number of complete detonations with each detonator was as follows:

Number of complete detonations in small lead block tests with a 40 per cent strength gelatin dynamite (frozen).

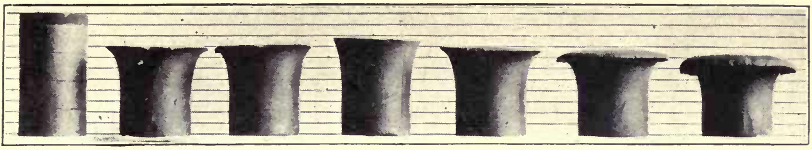
Grade of electric detonator.	Number of tests.	Number of tests in which complete detonation occurred.	Percentage of complete detonations.
			Per cent.
No. 3	5	4	80
No. 4	5	4	80
No. 5	5	4	80
No. 6	5	5	100
No. 7	5	5	100
No. 8	5	5	100

The results tabulated above indicate that the tendency to complete detonation increases with the grade of the electric detonator used.

EXPLOSION-BY-INFLUENCE TESTS.[a]

Explosion-by-influence tests were conducted by placing two cartridges of an explosive at a definite distance apart; each cartridge was in a vertical position, one being directly above the other. The electric detonator was placed in the lower end of the lower cartridge, so that the lower cartridge on detonation either did or did not cause

[a] For a more extended description of the test, see Bull. 15, Bureau of Mines: Investigations of explosives used in coal mines; with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe, by Clarence Hall, W. O. Snelling, and S. P. Howell, 1912, p. 100.

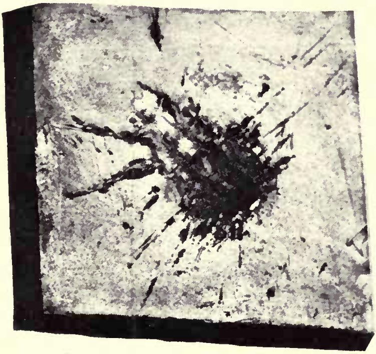


a 3 4 5 6 7 8

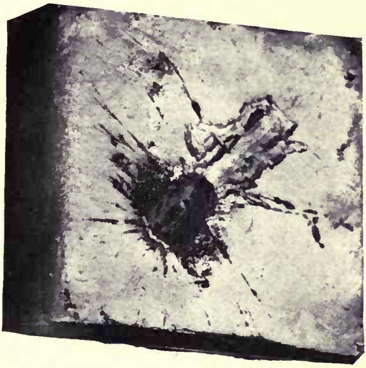
A. RESULTS OF SMALL LEAD BLOCK TESTS OF P. T. S. S. ELECTRIC DETONATORS NOS. 3, 4, 5, 6, 7, AND 8. *a*, BLOCK BEFORE TEST.

a *b* *c* *d* *e*

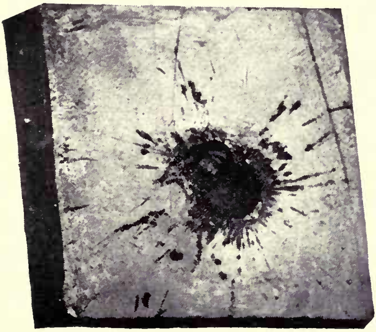
B. RESULTS OF SMALL LEAD BLOCK TESTS OF NO. 6 ELECTRIC DETONATORS. *a*, BLOCK BEFORE TEST; *b*, WESTERN COAST; *c*, SPECIAL; *d*, P. T. S. S.; *e*, FOREIGN.



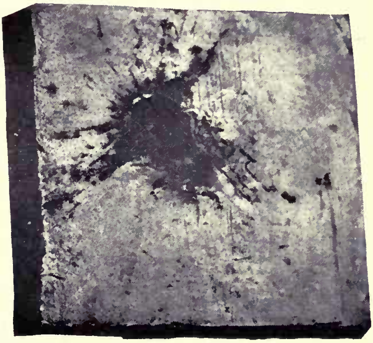
WESTERN COAST.



SPECIAL.



P. T. S. S.



FOREIGN.

C. SCORING OF LEAD PLATES BY FOUR NO. 6 ELECTRIC DETONATORS LAID ON SIDE.

detonation of the upper cartridge. The separating distance, established by successive trials, was but 1 inch greater than that at which the upper cartridge would detonate. With one explosive, however, certain trials were run with the cartridges separated by a given distance, and the number of times that the upper cartridge did or did not detonate was recorded.

TESTS WITH AN EXPLOSIVE OF CLASS 1, SUBCLASS *a*.

The results of tests with an explosive of class 1, subclass *a* (an ammonium-nitrate explosive containing a sensitizer that is itself an explosive), are tabulated below. The average weight of the cartridges was 166 grams and they measured 1¼ by 8 inches.

Results of explosion-by-influence tests with an explosive of class 1, subclass a.

Grade of electric detonator.	Test No.	Distance separating cartridges.	Result on upper cartridge.	Distance established at—
		Inches.		*Inches.*
No. 3	J874	3	Did not explode	4
	J875	2	Exploded	
	J876	3	....do	
	J877	4	Did not explode	
	J878	4	....do	
No. 4	J870	2	Exploded	4
	J871	3	....do	
	J872	4	Did not explode	
	J873	4	....do	
No. 5	J764	2	....do	2
	J765	1	Exploded	
	1766	2	Did not explode	
No. 6	J741	4	....do	3
	J742	3	....do	
	J743	2	....do	
	J744	1	Exploded	
	J745	2	....do	
	J746	3	Did not explode	
No. 7	J747	3	....do	3
	J748	2	Exploded	
	J749	3	Did not explode	
No. 8	J750	3	....do	3
	J751	2	Exploded	
	J752	3	Did not explode	

These tests did not discriminate as to the relative efficiency of the different grades of electric detonators; the efficiency of the low-grade electric detonators was at least as great as that of the high-grade electric detonators.

TESTS WITH AN EXPLOSIVE OF CLASS 4.

Following are the results of tests with an explosive of class 4 (an explosive in which the characteristic material is nitroglycerin). Except for the trials under test J896, the average weight of each cartridge was 161 grams and the size of each was 1¼ by 8 inches. In the trials under test J896 the lower cartridge weighed 161 grams and the upper one weighed 110 grams, being only 5 inches long. In all

of the tests in which the distance separating cartridges was 5 inches, the bottoms of the cartridges (as packed) faced each other, whereas in all of the tests in which the separating distance was 4 inches, the tops of the cartridges faced each other.

Results of explosion-by-influence tests with an explosive of class 4.

Grade of electric detonator.	Test No.	Distance separating cartridges.	Result—upper cartridge.
		Inches.	
No. 3	J895	5	Did not explode.
	J895	5	Do.
	J895	5	Exploded.
	J895	5	Did not explode.
	J896	4	Do.
	J896	4	Do.
	J896	4	Do.
No. 4	J895	5	Do.
	J895	5	Do.
	J895	5	Do.
	J895	5	Exploded.
	J896	4	Do.
	J896	4	Do.
	J896	4	Did not explode.
No. 5	J895	5	Do.
	J895	5	Do.
	J895	5	Do.
	J895	5	Exploded.
	J896	4	Did not explode.
	J896	4	Do.
	J896	4	Do.
No. 6	J895	5	Do.
	J895	5	Do.
	J895	5	Do.
	J895	5	Exploded.
	J896	4	Do.
	J896	4	Do.
	J896	4	Did not explode.
No. 7	J895	5	Do.
	J895	5	Do.
	J895	5	Do.
	J895	5	Exploded.
	J896	4	Do.
	J896	4	Do.
	J896	4	Did not explode.
No. 8	J895	5	Do.
	J895	5	Do.
	J895	5	Do.
	J895	5	Do.
	J896	4	Do.
	J896	4	Exploded.
	J896	4	Do.

The following tabulation shows the number of explosions of the upper cartridge:

Percentage of explosions of the upper cartridge in explosion-by-influence tests with an explosive of class 4.

Grade of electric detonator.	Number of tests.	Number of explosions of the second cartridge.	Percentage of explosions.
No. 3	7	1	14
No. 4	7	3	43
No. 5	7	1	14
No. 6	7	3	43
No. 7	7	3	43
No. 8	7	2	29

TESTS WITH A 40 PER CENT STRENGTH AMMONIA DYNAMITE CONTAINING NITROSUBSTITUTION COMPOUNDS.

Following are tabulated the results of tests with a 40 per cent strength ammonia dynamite containing nitrosubstitution compounds. The cartridges used were 1¼ by 8 inches, their average weight being 226 grams.

Results of explosion-by-influence tests with a 40 per cent strength ammonia dynamite containing nitrosubstitution compounds.

Grade of electric detonator.	Test No.	Distance separating cartridges.	Result on upper cartridge.	Distance established at—
		Inches.		*Inches.*
No. 5	J708	8	Exploded	9
	J709	9	Did not explode	
	J710	9	do	
No. 6	J689	14	do	8
	J690	12	do	
	J691	9	do	
	J692	7	do	
	J693	6	do	
	J694	4	Exploded	
	J695	5	do	
	J696	6	do	
	J697	7	do	
	J698	8	Did not explode	
	J699	8	do	
No. 7	J720	9	do	9
	J721	8	Exploded	
	J722	9	Did not explode	
No. 8	J704	8	Exploded	10
	J705	9	do	
	J706	10	Did not explode	
	J707	10	do	

No tests made with detonators Nos. 3 and 4.

TESTS WITH A 35 PER CENT STRENGTH GELATIN DYNAMITE 2 YEARS OLD.

Following are the results of tests with a 35 per cent strength gelatin dynamite (two years old). The average weight of each cartridge was 265 grams and the size of each 1¼ by 8 inches.

Results of explosion-by-influence tests with a 35 per cent strength gelatin dynamite (2 years old).

Grade of electric detonator.	Test No.	Distance separating cartridges.	Result on upper cartridge.
		Inches.	
No. 6	J724	6	Did not explode.
	J725	5	Do.
	J726	4	Do.
	J727	2	Do.
	J728	0	Do.
	J729	0	Do.
No. 7	J730	0	Do.
	J731	0	Do.
No. 8	J732	0	Do.
	J733	0	Do.

No tests were made with the No. 3, the No. 4, or the No. 5 electric detonators.

The tests failed to discriminate between the different grades of electric detonators, except to the limited extent that in two trials the lower cartridge failed to detonate completely once with the No. 6. In no trial did the detonation of the lower cartridge cause the detonation of the upper cartridge.

PERCENTAGES OF DETONATIONS IN INDIRECT TESTS OF P. T. S. S. ELECTRIC DETONATORS.

The percentages of detonations in the indirect tests of the P. T. S. S. electric detonators are given below. The percentages of detonations in the tests of each electric detonator are also averaged, each average percentage having a value proportional to the number of tests from which computed; that is, each percentage is multiplied by the number of tests it represents, and the sum of the products is divided by the total number of tests of the electric detonator considered.

Percentages of detonations in indirect tests of P. T. S. S. electric detonators.

Class of explosive.	Kind of test.	Grade of electric detonator.											
		No. 3.		No. 4.		No. 5.		No. 6.		No. 7.		No. 8.	
		Percentage of detonations.	Number of tests.	Percentage of detonations.	Number of tests.	Percentage of detonations.	Number of tests.	Percentage of detonations.	Number of tests.	Percentage of detonations.	Number of tests.	Percentage of detonations.	Number of tests.
		Per cent.		*Per cent.*		*Per cent.*		*Per cent.*		*Per cent.*		*Per cent.*	
Class 1, subclass *b*	Rate of detonation.	0	5	0	5	0	5	40	5	100	5	100	5
Class 1, subclass *a*	...do	67	3	100	2	50	2	100	2	100	2	100	2
40 per cent strength gelatin dynamite (frozen).	...do	0	1	100	1	100	1	100	1	100	1	100	1
35 per cent strength gelatin dynamite (two years old).	...do	100	1	100	2	50	4	67	3	100	3	100	4
20 per cent "straight" nitroglycerin dynamite (containing 6 per cent of added water and frozen).	Small lead block.	0	3	0	3	0	3	0	3	67	3	67	3
40 per cent strength gelatin dynamite (frozen).	...do	80	5	80	5	80	5	100	5	100	5	100	5
Total number of tests	....	....	18	....	18	....	20	....	19	....	19	....	20
Average percentage of detonations.	....	38.9	....	50.0	....	40.0	....	63.2	....	94.7	....	95.0	....

COMPARATIVE EXPLOSIVE EFFICIENCY.

The percentages of explosive efficiency of the different types of P. T. S. S. electric detonators were obtained by averaging all tests in which the rate of detonation or compression was determined for all the electric detonators. The percentages of the individual electric detonators were also averaged, each average percentage having a value proportional to the number of tests from which computed; that is, each percentage is multiplied by the number of tests it represents, and the sum of the products is divided by the total number of tests of the electric detonator considered. In each case the percentage of explosive efficiency of the No. 6 electric detonator is assigned a value of 100 and is used as the unit of comparison.

Explosive efficiency of P. T. S. S. electric detonators.

Class and grade of explosive.	Kind of test.	No. 3. Rate (meters per second).	No. 3. Compression.	No. 3. Percentage of explosive efficiency.	No. 3. Number of tests.	No. 4. Rate (meters per second).	No. 4. Compression.	No. 4. Percentage of explosive efficiency.	No. 4. Number of tests.	No. 5. Rate (meters per second).	No. 5. Compression.	No. 5. Percentage of explosive efficiency.	No. 5. Number of tests.	No. 6. Rate (meters per second).	No. 6. Compression.	No. 6. Percentage of explosive efficiency.	No. 6. Number of tests.	No. 7. Rate (meters per second).	No. 7. Compression.	No. 7. Percentage of explosive efficiency.	No. 7. Number of tests.	No. 8. Rate (meters per second).	No. 8. Compression.	No. 8. Percentage of explosive efficiency.	No. 8. Number of tests.
			Mm.	P. ct.			Mm.	P. ct.			Mm.	P. ct.			Mm.	P. ct.			Mm.	P. ct.			Mm.	P. ct.	
20 per cent "straight" nitroglycerin dynamite in ⅞-inch cartridges.	Rate of detonation.	2,962	......	97.2	2	2,852	......	93.6	2	2,928	......	96.1	2	3,046	......	100.0	3	2,993	......	98.3	2	3,000	......	98.5	2
35 per cent strength gelatin dynamite 2 years old in 1¼-inch cartridges.	....do....	a 6.5	......	37.1	1	a 7.5	......	42.9	1	a 13.0	......	74.3	2	a 17.5	......	100.0	2	a 12.0	......	68.6	3	a 14.8	......	84.6	4
20 per cent "straight" nitroglycerin dynamite (containing 6 per cent of added water).	Small lead block.	......	14.08	93.9	3	......	14.67	97.8	3	......	14.08	93.9	3	......	15.00	100.0	3	......	15.25	101.7	3	......	15.50	103.3	3
20 per cent "straight" nitroglycerin dynamite (containing 0 to 4 per cent of added water and frozen).	....do....	......	13.33	100.6	3	......	13.42	101.3	3	......	13.00	98.1	3	......	13.25	100.0	3	......	13.83	104.4	3	......	13.92	105.1	3
40 per cent strength gelatin dynamite (frozen).	....do....	......	14.25	95.3	4	......	12.62	81.7	4	......	13.12	87.8	4	......	14.95	100.0	5	......	17.00	113.7	5	......	17.80	119.1	5
40 per cent strength ammonia dynamite (containing 6 per cent of added water).	....do....	......	8.25	92.2	5	......	8.20	91.6	5	......	7.70	86.0	5	......	8.95	100.0	5	......	9.15	102.2	5	......	9.70	108.4	5
Average....	....	......	......	92.1	...	......	......	89.6	...	......	......	89.4	...	......	......	100.0	...	......	......	100.0	...	......	......	104.5	22
Total number of tests	....	......	......	......	18	......	......	......	18	......	......	......	19	......	......	......	21	......	......	......	21	......	......	......	...

a Inches that detonated.

Average explosive efficiency of electric detonators Nos. 3, 4, and 5 in 55 tests, 90.4.
Average explosive efficiency of electric detonators Nos. 6, 7, and 8 in 64 tests, 101.6.

COMPARATIVE EXPLOSIVE EFFICIENCY OF P. T. S. S. ELECTRIC DETONATORS.

The tabulation below shows the comparative explosive efficiency (fig. 3) of the six grades of P. T. S. S. electric detonators:

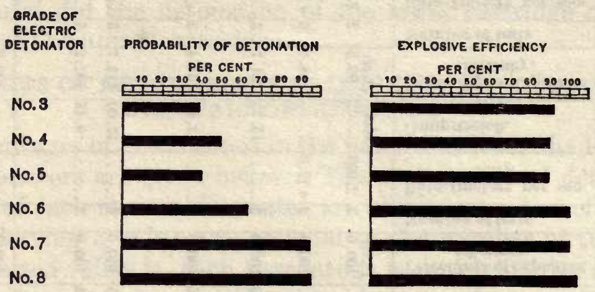


FIGURE 3.—Comparative explosive efficiency of six grades of P. T. S. S. electric detonators as determined by indirect tests.

Comparative explosive efficiency of six grades of P. T. S. S. electric detonators.

Grade of electric detonator.	Probability of detonation.	Explosive efficiency for those tests in which detonation occurred.
	Per cent.	*Per cent.*
No. 3	38.9	92.1
No. 4	50.0	89.6
No. 5	40.0	89.4
No. 6	63.2	100.0
No. 7	94.7	100.0
No. 8	95.0	104.5

TESTS OF FOUR NO. 6 ELECTRIC DETONATORS OF DIFFERENT MAKES.

In the tests of P. T. S. S. electric detonators as described above the composition of the fulminating charge was practically the same in each electric detonator, although there was variation in the weight of the charge. In the tests, the results of which are tabulated below, four No. 6 electric detonators manufactured by different makers were used. The weight of charge of each of the No. 6 electric detonators tested was approximately 1 gram, but each electric detonator had a different composition. The electric detonators were representative of all electric detonators used in the United States, and the tests made are of especial importance for the reason that they established for each electric detonator the charge equivalent to the Pittsburgh testing station standard electric detonators.

PHYSICAL EXAMINATION.

A physical examination was made of each of the four electric detonators (fig. 4), the results being given in the following tabulation. Each item represents an average of measurement of five electric detonators.

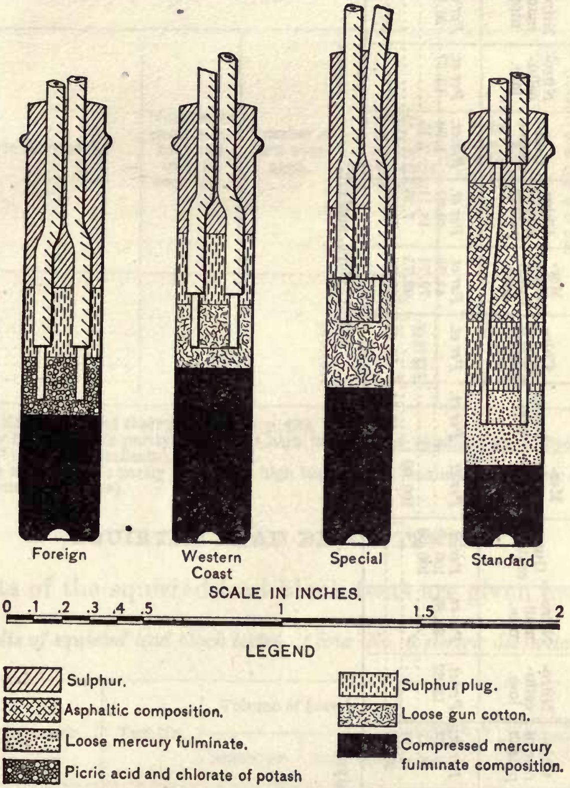


FIGURE 4.—Cross-sectional view of four No. 6 electric detonators of different makes.

Results of physical examination of four No. 6 electric detonators of different makes.

Kind of electric detonator.	Length of shell.	Outside diameter of shell.	Inside diameter of shell.	Thickness of shell.	Length of compressed charge.	Length of priming charge.	Length of sulphur plug.	Length of asphaltic composition, if any.	Length of sulphur filling.	Distance wires project below sulphur plug.	Distance from end of insulation to end of wires.
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
Western Coast	1.55	0.274	0.260	0.007	0.62	0.23	0.25	......	0.45	0.16	0.19
Special	1.75	.234	.220	.007	.56	.39	.25	......	.30	.16	.16
P. T. S. S	1.55	.274	.260	.007	.28	.27	.25	0.50	.25	.12	.94
Foreign	1.55	.274	.260	.007	.44	.21	.25	......	.65	.16	.19

WEIGHT AND COMPOSITION OF CHARGES.

Following is a tabulation presenting the weight of the charges and their chemical composition as determined by analysis:

Weight and composition of charges of four No. 6 electric detonators.

Kind of electric detonator.	Weight of compressed charge.	Weight of priming charge.	Weight of total charge.	Constituents in compressed charge.				Constituents in priming charge.				Constituents in total charge.						
				Mercury fulminate.	Chlorate of potash.	Nitrocellulose.	Nitromannite.	Guncotton.	Mercury fulminate.	Picric acid.	Chlorate of potash.	Mercury fulminate.	Chlorate of potash.	Guncotton.	Nitrocellulose.	Nitromannite.	Picric acid.	Total.
	Grams.	*Grams.*	*Grams*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Western Coast a	0.8527	0.0155	0.8682	45.57	19.72	13.82	20.89	100.00	....	....	....	44.76	19.37	1.79	13.57	20.51	....	100.00
Special a	.9083	.0200	.9283	81.49	18.51	....	....	100.00	....	....	....	79.74	18.11	2.15	....	....	....	100.00
P. T. S. b	.6485	.3510	.9995	88.82	11.18	....	....	....	100.00	....	....	92.75	7.25	....	....	....	....	100.00
Foreign a	1.0108	.1640	1.1748	79.47	20.53	....	....	....	....	40.54	59.46	68.38	25.96	....	....	....	5.66	100.00

a J. H. Hunter, analyst. b W. C. Cope, analyst.

RESULTS OF CALORIMETER TESTS.

The results of calorimeter tests of the four kinds of No. 6 electric detonator are tabulated below.

Results of calorimeter tests of four No. 6 electric detonators.

Kind of electric detonator.	Number of electric detonators used in each test.	Number of tests averaged.	Average heat evolved per electric detonator.	Total charge per electric detonator.	Average heat evolved per electric detonator had each contained the same weight of a charge consisting of 77.7 per cent of mercury fulminate and 22.3 per cent of chlorate of potash (exact combustion).[a]
			Large calories.	*Grams.*	*Large calories.*
Western Coast	15	2	[b] 0.95	0.8682	0.61
Special	15	2	.75	.9283	.66
P. T. S. S.	15	2	.62	.9995	.71
Foreign	15	3	[c] 1.12	1.1748	.83

[a] Berthelot, M., Explosives and their power, 1892, p. 470.
[b] This unusually high value is partly due to the high heat of total combustion of nitrocellulose (about three times that of mercury fulminate).
[c] This unusually high value is partly due to the high heat of total combustion of picric acid (about four times that of mercury fulminate).

SQUIRTED LEAD BLOCK TESTS.

The results of the squirted lead block tests are given herewith.

Results of squirted lead block tests[a] of four No. 6 electric detonators.

Kind of electric detonator.	Test No.	Volume of bore hole. Before test.	Volume of bore hole. After test.	Increase of volume.	Average increase of volume.	Weight of total charge.
		C. c.	*C. c.*	*C. c.*	*C. c.*	*Grams.*
Western Coast	AA14	1.7	27.7	26.0	26.5	0.8682
	AA15	1.7	28.7	27.0		
Special	AA 9	1.4	20.6	19.2	19.0	.9283
	AA41	1.5	19.3	18.8		
P. T. S. S	AA10	1.7	20.0	18.3	18.2	.9995
	AA11	1.7	19.8	18.1		
Foreign	AA12	1.7	28.9	27.2	27.0	1.1748
	AA26	1.7	28.6	26.9		

[a] For a description of the procedure in these tests, see p. 20.

CAST LEAD BLOCK TESTS.

Following are tabulated the results (Pl. VI) of cast lead block tests of the four kinds of No. 6 electric detonators:

Results of cast lead block tests of four No. 6 electric detonators.

Kind of electric detonator.	Test No.	Volume of bore hole.		Increase of volume.	Average increase of volume.	Weight of total charge.
		Before test.	After test.			
		C. c.	*C. c.*	*C. c.*	*C. c.*	*Grams.*
Western Coast	AA 6	1.8	22.7	20.9	21.2	0.8682
	AA31	1.7	23.2	21.5		
Special	AA33	1.4	16.1	14.7	14.2	.9283
	AA58	1.4	15.2	13.8		
P. T. S. S	AA30	1.7	16.0	14.3	14.0	.9995
	AA55	1.6	15.2	13.6		
Foreign	AA 5	1.7	19.7	18.0	18.2	1.1748
	AA54	1.7	20.0	18.3		

TESTS WITH LEAD PLATES.

Two series of tests of the four No. 6 electric detonators were made by the use of ½-inch lead plates. In one series the electric detonators were placed on end on the plates and were detonated, the resultant depression of the plates being recorded. In the other series each electric detonator was placed on its side on the lead plate before detonation.

DETONATORS ON END.

The results of the lead-plate tests in which the detonators were placed on end (Pl. VII) are tabulated below:

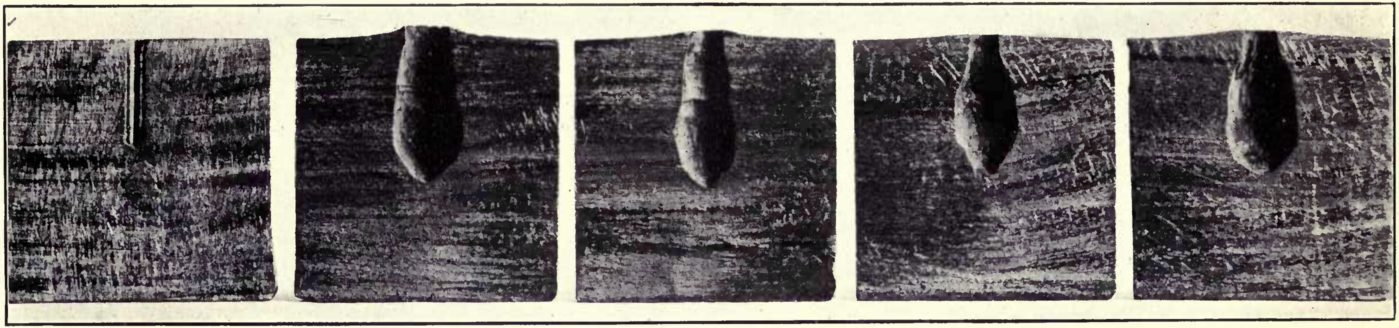
Results of lead-plate tests of four No. 6 electric detonators, detonators being placed on end.

Kind of electric detonator.	Test No.	Volume of water contained in depression.	Diameter of crater.	Depth of crater.	Height of cone on bottom.
		C. c.	*Mm.*	*Mm.*	*Mm.*
Western Coast	M155	0.15	11	5	Slight.
Special	M159	.25	11	6	2
P. T. S. S	M149	.40	13	7	3
Foreign	M153	.45	13	7	3

Results of lead-plate tests of four grades of electric detonators, detonators being placed on side.

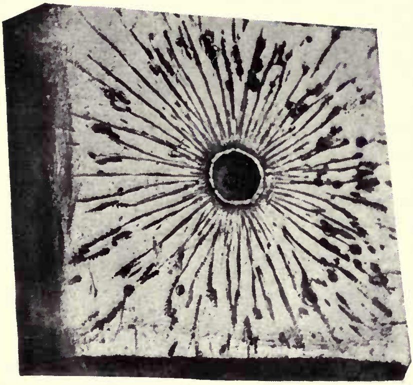
Kind of electric detonator.	Test No.	Volume of water contained in depression.	Diameter of crater.	Depth of crater.	Height of cone on bottom.
Western Coast	M156	0.45	26	12	4
Special	M160	.50	19	11	4
P. T. S. S	[a] M150	.50	21	13	5
Foreign	M154	.50	22	13	5

[a] Bottom of plate slightly raised; not raised in other tests.



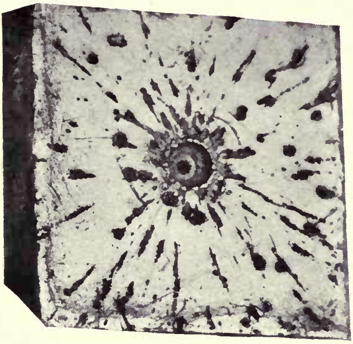
a *b* *c* *d* *e*

RESULTS OF CAST LEAD BLOCK TESTS OF FOUR NO. 6 ELECTRIC DETONATORS. *a*, LEAD BLOCK BEFORE TEST; *b*, WESTERN COAST; *c*, SPECIAL; *d*, P. T. S. S.; *e*, FOREIGN.

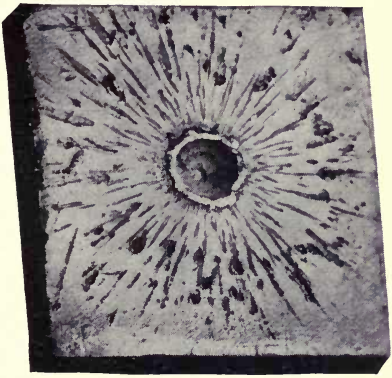


WESTERN COAST.

SPECIAL.



P. T. S. S.



FOREIGN

SCORING OF LEAD PLATES BY FOUR NO. 6 ELECTRIC DETONATORS PLACED ON END.

DETONATORS ON SIDE.

Following are tabulated the results when the detonators were placed on their side (Pl. V, *C*) on the lead plates before detonation:

A second series of tests with the ½-inch lead plates, the electric detonators being fired on their side, was made, and the resultant depressions of the plates were measured with sand. The results are tabulated below:

Depression of ½-inch lead plates when electric detonators were fired on their side, depression measured with sand.

Kind of electric detonator.	Test No.	Plate No.	Weight of sand contained in depression, measurement No.— 1	2	3	4	5	Average.	Grand average.	Volume.[a]
			Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*C. c.*
Western Coast....	M307	1	0.535	0.565	0.544	0.551	0.553	0.550	0.540	0.380
		2	.591	.601	.602	.560	.602	.591		
		3	.476	.470	.489	.472	.485	.478		
Special..........	M307	1	.507	.557	.562	.540	.587	.551	.556	.392
		2	.551	.563	.566	.573	.590	.569		
		3	.540	.536	.568	.542	.551	.547		
P. T. S. S........	M301	1	.574	.565	.620	.620	.590	.594	.596	.420
		2	.580	.586	.607	.569	.596	.588		
		3	.622	.600	.615	.601	.598	.607		
Foreign..........	M307	1	.635	.668	.678	.684	.573	.648	.595	.419
		2	.602	.584	.594	.587	.610	.595		
		3	.580	.560	.540	.511	.520	.542		

[a] The volume was computed from the grand average by dividing this by the specific gravity of the sand—in this case 1.42.

The results of the tests are fairly satisfactory, as they practically agree with the explosive efficiency established for electric detonators by the indirect methods.

NAIL TESTS.

The nail tests previously described were also used in connection with the investigation of the four grades of No. 6 electric detonators. The results (Pl. IV, *B*) are tabulated below:

Results of nail tests of four No. 6 electric detonators.

Kind of electric detonator.	Test No.	Angle of bending resulting from trial No.— 1	2	3	4	5	Average.	Minimum.
		°	°	°	°	°	°	°
Western Coast..................	M286	22	24	20	28	27	24.2	20
Special..........................	M287	16	35	17	16	23	21.4	16
P. T. S. S......................	M288	23	24	25	24	26	24.4	23
Foreign.........................	M300	17	31	18	19	18	20.6	17

RATE-OF-DETONATION TESTS.

Rate-of-detonation tests similar to those with the different grades of P. T. S. S. electric detonators were conducted with the four No. 6 electric detonators. The results, according to the explosive used, are presented below.

TESTS WITH AN EXPLOSIVE OF CLASS 1, SUBCLASS *a*.

Following are the results of tests with an explosive of class 1, subclass *a* (an ammonium-nitrate explosive containing a sensitizer that is itself a sensitizer). The diameter of the cartridges used was seven-eighths of an inch.

Results of rate-of-detonation tests with an explosive of class 1, subclass a.

Kind of electric detonator.	Test No.	Rate of detonation in tube.							
		First quarter.		Second quarter.		Second half.		Full length.	
		Individual rate.	Average rate.	Individual rate.	Average rate.	Individual rate.	Average rate.	Individual rate.	Average rate.
		Meters per second.	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*
Western Coast	D970 D971	2,343 2,295	2,319	2,295 2,250	2,272	2,585 2,556	2,570	2,445 2,406	2,426
Special	D976 D978 D979	1,891 2,419 2,393	2,234	2,296 2,393 2,206	2,298	2,761 2,459 2,419	2,546	2,368 2,432 2,356	2,385
P. T. S. S	D966 D967	2,445 2,472	2,458	2,678 2,586	2,632	2,205 2,205	2,205	2,368 2,356	2,362
Foreign	D974 D973	2,778 2,143	2,460	1,814 2,393	2,104	2,795 2,866	2,830	2,459 2,528	2,494
Grand average			2,393		2,326		2,538		2,417

The average rate for the meter length was practically uniform, but such difference as was shown indicated that the ascending order of explosive efficiency of the detonators is as follows: P. T. S. S., special, Western Coast, foreign.

The percentage of complete detonations with each detonator was as follows:

Percentage of complete detonations with an explosive of class 1, subclass a.

Kind of electric detonator.	Number of tests.	Number of tests in which incomplete detonation occurred.	Percentage of complete detonations.
			Per cent.
Western Coast	2	0	100
Special	5	0	100
P. T. S. S	2	0	100
Foreign	3	1	67

TESTS WITH AN EXPLOSIVE OF CLASS 1, SUBCLASS *b*.

Two rate-of-detonation tests were made of each of the four kinds of No. 6 electric detonators on an explosive of class 1, subclass *b* (an ammonium-nitrate explosive containing a sensitizer that is not itself an explosive) being used. The cartridges used were 1¾ inches in diameter. In no test did detonation occur, so that the tests failed to discriminate between the different kinds of electric detonators.

TESTS WITH A 20 PER CENT "STRAIGHT" NITROGLYCERIN DYNAMITE.

The results of tests with a 20 per cent "straight" nitroglycerin dynamite are presented below. The diameter of the cartridges was seven-eighths of an inch.

Results of rate-of-detonation tests with a 20 per cent "straight" nitroglycerin dynamite.

Kind of electric detonator.	Test No.	Rate of detonation in tube.							
		First quarter.		Second quarter.		Second half.		Full length.	
		Individual rate.	Average rate.	Individual rate.	Average rate.	Individual rate.	Average rate.	Individual rate.	Average rate.
		Meters per second.	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*
Western Coast	D996 D997	2,778 3,462	3,120	2,960 2,679	2,820	3,147 3,285	3,216	3,000 3,147	3,074
Special	D998 D999	3,048 3,299	3,174	2,928 2,587	2,758	3,069 3,027	3,048	3,027 2,967	2,997
P. T. S. S	D1000 D1002	3,729 3,947	3,838	2,683 2,443	2,563	2,767 3,309	3,038	2,933 3,158	3,046
Foreign	D994 D995	2,922 3,000	2,961	3,125 2,557	2,841	2,866 3,061	2,964	2,941 2,903	2,922
Grand average	....	....	3,273	....	2,746	....	3,066	....	3,010

The figures representing the grand averages indicate that the rate was influenced by a negative acceleration in the second quarter meter followed by a positive acceleration in the second half meter. This acceleration occurred in all tests except D996 and D994.

The uniformity of the rates for the last half meter and the meter is noteworthy.

With a 20 per cent "straight" nitroglycerin dynamite such difference as was shown in the tests indicated that the ascending order of explosive efficiency is: Foreign, special, P. T. S. S., Western Coast.

TESTS WITH A 40 PER CENT STRENGTH AMMONIA DYNAMITE CONTAINING NITROSUBSTITUTION COMPOUNDS.

Following are tabulated the results of tests with a 40 per cent ammonia dynamite containing nitrosubstitution compounds. The explosive was repacked in cartridges seven-eighths of an inch in diameter.

Results of rate-of-detonation tests with a 40 per cent strength ammonia dynamite containing nitrosubstitution compounds.

Kind of electric detonator.	Test No.	Rate of detonation in tube. First quarter. Individual rate.	First quarter. Average rate.	Second quarter. Individual rate.	Second quarter. Average rate.	Second half. Individual rate.	Second half. Average rate.	Full length. Individual rate.	Full length. Average rate.
		Meters per second.	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*	*Meters per second.*
Western coast	D913 D923	2,557 3,082	2,820	2,394 2,500	2,447	2,812 2,616	2,714	2,632 2,687	2,660
Special	D879 D914	2,820 2,587	2,704	2,588 2,781	2,684	2,900 3,048	2,974	2,794 2,853	2,824
P. T. S. S	D904 D919 D920	2,368 2,472 2,250	2,363	2,296 3,041 2,446	2,594	2,572 2,663 2,543	2,593	2,446 2,695 2,439	2,527
Foreign	D912 D922	2,250 2,616	2,433	3,129 3,125	3,127	2,446 2,557	2,502	2,528 2,542	2,535

The rate for the second quarter meter was the highest for the P. T. S. S. and the foreign electric detonators.

With a 40 per cent strength ammonia dynamite containing nitrosubstitution compounds the tests indicated that the ascending order of explosive efficiency is: P. T. S. S., foreign, Western Coast, special.

TESTS WITH A 35 PER CENT STRENGTH GELATIN DYNAMITE 2 YEARS OLD.

The results of tests with a 35 per cent strength gelatin dynamite (two years old) are tabulated below. The diameter of the cartridges used was $1\frac{1}{4}$ inches.

Results of rate-of-detonation tests with a 35 per cent strength gelatin dynamite two years old.

Kind of electric detonator.	Test No.	Length [a] of part of file blown off or detonated.	Percentage of file that detonated.	Average.	Remarks.
		Inches.	*Per cent.*	*Per cent.*	
Western Coast	D897 D898	7.0 8.0	17 19	18.0	Partial detonation. Do.
Special	D901 D902	10.0 9.0	24 21	22.5	Do. Do.
P. T. S. S	D889 D896 D958	7.0 18.0 17.0	0 43 40	27.5	No detonation. Partial detonation. Do.
Foreign	D899 D900	6.0 7.0	14 17	15.5	Do. Do.

[a] Full length of file, 42 inches.

The evidence of no detonation in test D889 was that nothing but the noise of the electric detonator was audible when the trial was made.

With the two-year-old sample of 35 per cent strength gelatin dynamite used the tests indicated that the ascending order of explosive efficiency is: Foreign, Western Coast, special, P. T. S. S.

The percentage of partial detonations with each electric detonator was as follows:

Percentage of partial detonations with a 35 per cent strength gelatin dynamite two years old.

Kind of electric detonator.	Number of tests.	Number of tests in which partial detonation occurred.	Percentage of complete detonations.
			Per cent.
Western Coast	2	2	100
Special	2	2	100
P. T. S. S	3	2	67
Foreign	2	2	100

TESTS WITH A 40 PER CENT STRENGTH GELATIN DYNAMITE, FROZEN.

Following are the results of tests with a 40 per cent strength gelatin dynamite (frozen). The diameter of the cartridges used was 1¼ inches.

Results of rate-of-detonation tests with a 40 per cent strength gelatin dynamite, frozen.

Kind of electric detonator.	Test No.	Rate of detonation in tube.			
		First quarter.	Second quarter.	Second half.	Full length.
		Meters per second.	*Meters per second.*	*Meters per second.*	*Meters per second.*
Western Coast	D1091	3,273	7,177	5,705	5,028
Special	D1092	4,167	6,357	6,013	5,460
P. T. S. S	D1093	4,167	7,759	6,522	5,921
Foreign	D1090	3,090	14,833	5,361	5,235
Grand average		3,674	9,032	5,900	5,411

The figures included in the "grand average" show that the maximum rate occurred in the second quarter, with a subsequent falling off in the rate; moreover, the rate varied similarly in each individual test.

With the explosive used in the tests the results indicate that the ascending order of explosive efficiency is: Western Coast, foreign, special, P. T, S. S.

TESTS WITH A 35 PER CENT STRENGTH GELATIN DYNAMITE 3 YEARS OLD.

One test each of the Western Coast, the special, and the foreign No. 6 electric detonators was made with a 35 per cent strength gelatine dynamite 3 years old. The diameter of the cartridges used was 1½ inches. No detonation took place in any of the tests, as the explosive was so old and insensitive to detonation that for the purpose of discriminating between detonators it was useless.

SMALL LEAD BLOCK TESTS.

Small lead block tests were made with the four No. 6 electric detonators. The results, according to the explosive tested, are given below.

TESTS WITH A 20 PER CENT "STRAIGHT" NITROGLYCERIN DYNAMITE.

Three series of tests were conducted with a 20 per cent "straight" nitroglycerin dynamite in different conditions as indicated below.

Results of small lead block tests with a 20 per cent "straight" nitroglycerin dynamite with 6 per cent of added water.

Kind of electric detonator.	Test No.	Compression.	Average compression.
		Mm.	Mm.
Western Coast	B759 B768 B777	15.00 14.75 15.25	15.00
Special	B760 B769 B778	14.00 15.25 15.25	14.83
P. T. S. S	B761 B770 B779	15.00 15.00 15.00	15.00
Foreign	B758 B767 B776	14.25 14.75 15.00	14.67

In the tests the explosive produced nearly uniform individual compressions and little difference in the average compressions, but such difference as was shown indicated that the ascending order of explosive efficiency is: Foreign, special, Western Coast, P. T. S. S.

The results of tests with the same explosive, but containing 4 per cent of added water and frozen, were as follows:

Results of small lead-block tests with a 20 per cent "straight" nitroglycerin dynamite containing 4 per cent of added water and frozen.

Kind of electric detonator.	Test No.	Temperature of frozen explosive.	Percentage of water added.	Compression.	Average compression.
		°C.		Mm.	Mm.
Western Coast	B651	−9.0	4.0	12.75	12.75
Special	B652	−9.0	4.0	12.50	12.50
P. T. S. S	B653	−9.0	4.0	13.00	13.00
Foreign	B650	−9.0	4.0	12.75	12.75

With the explosive in the condition mentioned, the results of the tests indicate that the ascending order of explosive efficiency is: Special, Western Coast, foreign, and P. T. S. S.

Further tests were conducted with 6 per cent of water added to the explosive and the explosive frozen (temperature 9° C.). Three tests were made with each of the four grades of electric detonators, but the explosive was too insensitive to detonation to be discriminative, as no compression of any of the blocks was produced.

TESTS WITH A 40 PER CENT STRENGTH AMMONIA DYNAMITE.

Following are the results of tests with a 40 per cent ammonia dynamite, to which had been added 6 per cent of water:

Results of small lead block tests with a 40 per cent strength ammonia dynamite containing 6 per cent of added water.

Kind of electric detonator.	Test No.	Compression.	Average compression.
		Mm.	*Mm.*
Western Coast	B660	8.25	8.75
	B669	9.00	
	B678	9.00	
	B687	8.00	
	B696	9.50	
Special	B661	8.00	8.40
	B670	8.25	
	B679	8.50	
	B688	7.75	
	B697	9.25	
P. T. S. S	B662	9.75	8.95
	B671	8.75	
	B680	9.25	
	B689	7.75	
	B698	9.25	
Foreign	B659	8.00	9.20
	B668	10.00	
	B677	9.25	
	B686	9.50	
	B695	9.25	

The results were obviously erratic. However, the tests indicated that the ascending order of explosive efficiency is: Special, Western Coast, P. T. S. S., foreign.

TESTS WITH A 40 PER CENT STRENGTH GELATIN DYNAMITE, FROZEN.

The results of tests with a 40 per cent strength gelatin dynamite (frozen) were as follows (Pl. V, *B*):

Results of small lead block tests with a 40 per cent strength gelatin dynamite, frozen.

Kind of electric detonator.	Test No.	Temperature of frozen explosive.	Compression.	Average compression.
		°*C.*	*Mm.*	*Mm.*
Western Coast	B635	−2.5	14.75	13.90
	B642	−5.0	17.75	
	B705	+ .5	12.50	
	B714	+2.5	12.50	
	B723	+2.5	12.00	
Special	B636	−2.5	12.75	14.85
	B643	−5.0	18.00	
	B706	+ .5	15.00	
	B715	+2.5	14.75	
	B724	+2.5	13.75	
P. T. S. S	B631	−4.5	12.50	14.95
	B644	−5.0	19.25	
	B707	+ .5	14.25	
	B716	+2.5	14.25	
	B725	+2.5	14.50	
Foreign	B634	−2.5	11.00	15.15
	B641	−5.0	18.00	
	B704	+ .5	15.00	
	B713	+2.5	16.25	
	B722	+2.5	15.50	

As indicated by the table, the results of the tests were very erratic with this frozen gelatin dynamite. The insensitiveness of this explosive has been mentioned in a foregoing section regarding the incompleteness of detonation in tests with the Nos. 3, 4, and 5 electric detonators. With the No. 6 electric detonators, however, detonation was complete in every trial.

EXPLOSION-BY-INFLUENCE TESTS.

Tests involving explosion by influence as outlined in a foregoing section relative to tests of different grades of P. T. S. S. electric detonators were made of the four kinds of No. 6 electric detonators, as described below:

TESTS WITH AN EXPLOSIVE OF CLASS 1, SUBCLASS *a*.

Following are the results of tests with an explosive of class 1, subclass *a* (an ammonium-nitrate explosive containing a sensitizer that is itself an explosive). The size of the cartridges used was 1¼ by 8 inches and the average weight was 166 grams.

Results of explosion-by-influence tests with an explosive of class 1, subclass a (sample 1).

Kind of electric detonator.	Test No.	Distance separating cartridges.	Result on upper cartridge.	Established distance at which detonation did not occur.
		Inches.		*Inches.*
Western Coast	J758	2	Did not explode	2
	J759	1	Exploded	
	J760	2	Did not explode	
Special	J761	1	Exploded	2
	J762	2	Did not explode	
	J763	2	....do	
P. T. S. S	J741	4	....do	3
	J742	3	....do	
	J743	2	....do	
	J744	1	Exploded	
	J745	2	....do	
	J746	3	Did not explode	
Foreign	J753	3	....do	1
	J754	2	....do	
	J755	1	....do	
	J756	0	Exploded	
	J757	1	Did not explode	

With the ammonium-nitrate explosive used, the results of the tests indicated that the ascending order of explosive efficiency is: Foreign, Western Coast and special, P. T. S. S.

TESTS WITH AN EXPLOSIVE OF CLASS 4.

The results of tests with an explosive of class 4 (an explosive in which the characteristic material is nitroglycerin) are tabulated below. The size of the cartridges used was 1¼ by 8 inches, their average weight being 161 grams, except that in the trials under test J896 the upper cartridge weighed 110 grams and was 5 inches long.

Results of explosion-by-influence tests with an explosive of class 4.

Kind of electric detonator.	Test No.	Distance separating cartridges.	Result on upper cartridge.
		Inches.	
Western Coast	J895	5	Exploded.
	J895	5	Did not explode.
	J895	5	Do.
	J895	5	Do.
	J896	4	Exploded.
	J896	4	Do.
	J896	4	Did not explode.
Special	J895	5	Exploded.
	J895	5	Did not explode.
	J895	5	Do.
	J895	5	Do.
	J896	4	Exploded.
	J896	4	Do.
	J896	4	Did not explode.
P. T. S. S	J895	5	Do.
	J895	5	Do.
	J895	5	Do.
	J895	5	Exploded.
	J896	4	Do.
	J896	4	Do.
	J896	4	Did not explode.
Foreign	J895	5	Do.
	J895	5	Do.
	J895	5	Do.
	J895	5	Do.
	J896	4	Do.
	J896	4	Do.
	J896	4	Do.

Percentage of explosions of the upper cartridge in explosion-by-influence tests with an explosive of class 4.

Kind of electric detonator.	Number of tests.	Number of explosions of upper cartridge.	Percentage of explosions of upper cartridge.
			Per cent.
Western Coast	7	3	43
Special	7	3	43
P. T. S. S	7	3	43
Foreign	7	0	0

In all tests in which the distance separating cartridges was 5 inches the bottoms of the cartridges (as packed) faced each other; in all tests in which the distance was 4 inches the tops of the cartridges faced each other.

The tests indicated that the foreign electric detonator was not as effective under the conditions of the tests as were the other three.

TESTS WITH A 40 PER CENT STRENGTH AMMONIA DYNAMITE CONTAINING NITROSUBSTITUTION COMPOUNDS.

Following are the results of tests with a 40 per cent strength ammonia dynamite containing nitrosubstitution compounds. The cartridges used measured 1¼ by 8 inches and their average weight was 226 grams.

Results of explosion-by-influence tests with a 40 per cent strength ammonia dynamite containing nitrosubstitution compounds.

Kind of electric detonator.	Test No.	Distance separating cartridges.	Result on upper cartridge.	Distance at which detonation did not occur.
		Inches.		*Inches.*
Western Coast	J714	8	Exploded	9
	J715	9	Did not explode	
	J716	9	do	
Special	J717	8	do	8
	J718	7	Exploded	
	J719	8	Did not explode	
P. T. S. S	J689	14	do	8
	J690	12	do	
	J691	9	do	
	J692	7	do	
	J693	6	do	
	J694	4	Exploded	
	J695	5	do	
	J696	6	do	
	J697	7	do	
	J698	8	Did not explode	
	J699	8	do	
Foreign	J711	8	do	8
	J712	7	Exploded	
	J713	8	Did not explode	

The tests show practically the same result regardless of the electric detonator used.

TESTS WITH A 35 PER CENT STRENGTH GELATIN DYNAMITE 2 YEARS OLD.

The results of tests with a 35 per cent strength gelatin dynamite (two years old) are tabulated below. The cartridges used were 1¼ by 8 inches, their average weight being 265 grams.

Results of explosion-by-influence tests with a 35 per cent strength gelatin dynamite (two years old).

Kind of electric detonator.	Test No.	Distance separating cartridges.	Result on upper cartridge.
		Inches.	
Western Coast	J734	0	Did not explode.
	J735	0	Do.
Special	J737	0	Do.
	J738	0	Do.
P. T. S. S	J724	6	Do.
	J725	5	Do.
	J726	4	Do.
	J727	2	Do.
	J728	0	Do.
	J729	0	Do.
Foreign	J736	0	Do.
	J739	0	Do.

These tests failed to discriminate between the different detonators, as in no trial did the explosion of the lower cartridge cause the detonation of the upper cartridge.

TRAUZL LEAD BLOCK TESTS.[a]

In testing the four kinds of No. 6 electric detonators the Trauzl lead block tests were used in addition to the tests previously described. The Trauzl lead blocks are cylindrical in shape, measuring 200 mm. in diameter and 200 mm. in height. They have an axial bore hole 25 mm. in diameter and 125 mm. in depth. The charge of 20 grams of the explosive in which the electric detonator was embedded was placed in the bottom of the bore hole and no stemming was used. The increase in the volume of water that the bore hole would contain after an explosion was the result recorded.

Following is a tabulation of results of Trauzl lead block tests in which a 20 per cent "straight" nitroglycerin dynamite was used. The charge of explosive in each test was 20 grams, to which was added 6 per cent of water.

Results of Trauzl lead block tests with a 20 per cent "straight" nitroglycerin dynamite.

Kind of electric detonator.	Test No.	Expansion.	Average expansion.
		C. c.	*C. c.*
Western Coast	A817	175	174
	A818	173	
Special	A819	177	176
	A821	175	
P. T. S. S	A822	178	176
	A824	175	
Foreign	A815	178	178
	A816	179	

As indicated by the table, the average expansion of the blocks in each test was nearly the same.

PERCENTAGES OF DETONATIONS IN INDIRECT TESTS OF FOUR KINDS OF NO. 6 ELECTRIC DETONATORS.

The percentages of detonations in the indirect tests of the four kinds of No. 6 electric detonators are given below. The percentages of detonations in the tests of each electric detonator are also averaged, each average percentage having a value proportional to the number of tests from which it is computed; that is, each percentage is multiplied by the number of tests it represents and the sum of the products is divided by the total number of tests of the electric detonator considered.

[a] For a more extended description of this test see Bull. 15, Bureau of Mines: Investigations of explosives used in coal mines; with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe, by Clarence Hall, W. O. Snelling, and S. P. Howell, 1912, pp. 114-116.

Percentages of detonations in indirect tests of four kinds of No. 6 electric detonators.

Class and grade of explosive.	Character of test.	Western Coast.		Special.		P. T. S. S.		Foreign.	
		Percentage of detonations.	Number of tests.	Percentage of detonations.	Number of tests.	Percentage of detonations.	Number of tests.	Percentage of detonations.	Number of tests.
		Per ct.		*Per ct.*		*Per ct.*		*Per ct.*	
Class 1, subclass *a* (sample 1).	Rate of detonation.	100	2	100	5	100	2	67	3
40 per cent strength gelatin dynamite (frozen).	.....do.......	100	1	100	1	100	1	100	1
35 per cent strength gelatin dynamite (2 years old).	.....do.......	100	2	100	2	67	3	100	2
20 per cent "straight" nitroglycerin dynamite (frozen and containing 6 per cent of added water).	Small lead block.	0	3	0	3	0	3	0	3
40 per cent strength gelatin dynamite (frozen).	.....do.......	100	5	100	5	100	5	100	5
Average........	....	55.5	....	71.4	....	63.2	....	61.1	....
Total number of tests..	....	....	18	....	21	....	19	....	18

COMPARATIVE EXPLOSIVE EFFICIENCY.

The percentage of explosive efficiency of the four kinds of No. 6 electric detonators was obtained by averaging all tests in which the rate of detonation, compression, or expansion was determined for all detonators. Each percentage was given a value proportional to the number of tests from which the percentage was computed. In each case the percentage of explosive efficiency of the P. T. S. S. No. 6 electric detonator is given a value of 100 and is taken as the unit of comparison.

Explosive efficiency of four No. 6 electric detonators of different makes.

Class of explosive.	Kind of test.	Kind of electric detonator.																			
		Western Coast.					Special.					P. T. S. S.					Foreign.				
		Rate.	Compression.	Expansion.	Percentage of explosive efficiency.	Number of tests.	Rate.	Compression.	Expansion.	Percentage of explosive efficiency.	Number of tests.	Rate.	Compression.	Expansion.	Percentage of explosive efficiency.	Number of tests.	Rate.	Compression.	Expansion.	Percentage of explosive efficiency.	Number of tests.
		Meters per sec.	*Mm.*	*Cu. mm.*	*Per cent.*		*Meters per sec.*	*Mm.*	*Cu. mm.*	*Per cent.*		*Meters per sec.*	*Mm.*	*Cu. mm.*	*Per cent.*		*Meters per sec.*	*Mm.*	*Cu. mm.*	*Per cent.*	
20 per cent "straight" nitroglycerin dynamite in $\frac{7}{8}$-inch cartridges.	Rate-of-detonation.	3,074	......	......	100.9	2	2,997	......	......	98.4	2	3,046	......	......	100.0	2	2,922	......	......	95.9	2
40 per cent strength ammonia dynamite (containing nitrosubstitution compounds) in $\frac{7}{8}$-inch cartridges.	do	2,660	......	......	105.3	2	2,824	......	......	111.8	2	2,527	......	......	100.0	3	2,535	......	......	100.3	2
Class 1, subclass *a* (sample 1) in $\frac{7}{8}$-inch cartridges	do	2,426	......	......	102.7	2	2,385	......	......	101.0	3	2,362	......	......	100.0	2	2,494	......	......	105.5	2
40 per cent strength gelatin dynamite (frozen in $1\frac{1}{4}$-inch cartridges).	do	5,028	......	......	84.9	1	5,460	......	......	92.2	1	5,921	......	......	100.0	1	5,235	......	......	88.4	1
35 per cent strength gelatin dynamite (2 years old)	do	[a] 7.5	......	......	42.9	2	[a] 9.5	......	......	54.3	2	[a] 17.5	......	......	100.0	2	[a] 6.5	......	......	37.1	2
20 per cent "straight" nitroglycerin dynamite (containing 6 per cent of added water).	Small lead block.	......	15.00	......	100.0	3	......	14.83	......	98.9	3	......	15.00	......	100.0	3	......	14.67	......	97.8	3
20 per cent "straight" nitroglycerin dynamite (containing 4 per cent of added water).	do	......	12.75	......	98.1	1	......	12.50	......	96.2	1	......	13.00	......	100.0	1	......	12.75	......	98.1	1
40 per cent strength gelatin dynamite (frozen)	do	......	13.90	......	93.0	5	......	14.85	......	99.3	5	......	14.95	......	100.0	5	......	15.15	......	101.3	5
40 per cent strength ammonia dynamite (containing 6 per cent of added water).	do	......	8.75	......	97.8	5	......	8.40	......	93.9	5	......	8.95	......	100.0	5	......	9.20	......	102.8	5
20 per cent "straight" nitroglycerin dynamite (containing 6 per cent of added water).	Trauzl lead block.	......	......	174	98.9	2	......	......	176	100.0	2	......	......	176	100.0	2	......	......	178	101.1	2
Average					93.5					95.5					100.0					95.2	
Total number of tests						25					26					20					25

[a] Inches that detonated.

COMPARATIVE EXPLOSIVE EFFICIENCY OF FOUR KINDS OF NO. 6 ELECTRIC DETONATORS.

The comparative explosive efficiency of the four grades of electric detonators (fig. 5), as established, is tabulated below.

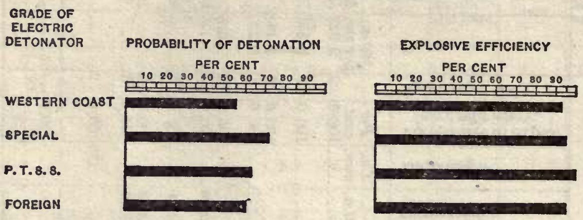


FIGURE 5.—Comparative explosive efficiency of four kinds of No. 6 electric detonators as established by indirect tests.

Explosive efficiency of four kinds of No. 6 electric detonators.

Kind of electric detonator.	Percentage of probability of detonation.	Explosive efficiency for those tests in which detonation occurred.
	Per cent.	*Per cent.*
Western Coast	55.5	93.5
Special	71.4	95.5
P. T. S. S. No. 6	63.2	100.0
Foreign	61.1	95.2

RELATIVE STRENGTH OF DETONATORS AND ELECTRIC DETONATORS.

It is generally recognized that the safest way of firing shots in blasting operations is with electric detonators by means of the electric current. This is especially true in gaseous coal mines, because if fuse is used the flame produced by the burning fuse may ignite such inflammable gaseous mixtures as are present. There is also danger of a hangfire when the charge may be exploded unexpectedly, due to the smoldering of the fuse.

There are, however, many conditions of mining under which electric detonators can not be used advantageously. In driving drifts in many of the metal mines of this country fuse is generally used. In work of this kind it is often necessary to fire dependent shots, and the flying rock from one shot may disconnect or cause short-circuiting of the electric wires of the detonators wired for succeeding shots. When fuse is used, different lengths can be cut and, before lighting, the projecting ends can be coiled in a place within the mouth of the hole where they are well protected.

It has been observed that mercury fulminate ignited in small quantities develops its full force only when confined. It also has been believed that the sulphur plug in an electric detonator

offers more confinement to the fulminating composition of a detonator than a piece of fuse does, even when the fuse is properly used and securely crimped in place. Therefore it seemed desirable to make comparative efficiency tests of both electric detonators and detonators fitted with fuse. The nail test was adopted for the reason that it produced more nearly the results established for the efficiency of detonators than any of the other direct methods.

The nail test was made with the No. 3 and the No. 6 detonators and with the electric detonators made from these detonators, with the following results:

Results of nail tests with No. 3 and No. 6 detonators and electric detonators.

Grade of detonator or electric detonator.	Test No.	Degrees of bending in trial—					Average.	Minimum.
		1	2	3	4	5		
		°	°	°	°	°	°	°
No. 3 detonator [a]	M289	8	7	9	9	8	8.2	7
No. 3 electric detonator	M279	12	10	8	9	7	9.2	7
No. 6 detonator [a]	M318	32	29	35	30	31	31.4	29
No. 6 electric detonator	M321	31	31	33	36	27	31.6	27

[a] Fired with fuse placed against the compressed charge of mercury fulminate composition and crimped in place.

The compressed charge of the No. 6 electric detonator weighed 1.0225 grams and consisted of 89.61 per cent of mercury fulminate and 10.39 per cent of potassium chlorate. The priming charge consisted of 0.02 gram of loose guncotton. As the weight of charge of this electric detonator was practically the same as of the P. T. S. S. electric detonator, the increased strength as shown by the nail test (nail bent 31.6° by the No. 6 electric detonator as compared with 24.4° by the P. T. S. S. electric detonator) would indicate that the quantity of compressed charge in the detonator may be a function of the efficiency of the detonator.

The tests showed that with low-grade detonators the strength of electric detonators is slightly greater than that of the corresponding detonators, but that with greater charges, such as the No. 6 detonators contain, the strength of the two types is practically the same. This indicates that the additional confinement given by the plug of the electric detonator as compared with the fuse of the fuse detonator is important only with the low-grade detonators.

A serious objection to the use of fuse and detonators in wet blasting is the fact that it is impossible to perfect a waterproof seal at the top of the detonator when it is crimped on the fuse. The ordinary fuse crimper depends on flattening the sides of the copper shell to contract the diameter of the detonator. Tests have shown that when a detonator is crimped on a fuse in this manner and submerged under

water for 30 minutes the fulminating charge and the powder train at the end of the fuse in the detonator become damp. The spit of the lighted fuse, if the fuse burns through, is usually of insufficient intensity to cause an explosion of the fulminating charge. In some cases a sharp explosion or an explosion of a very low order occurs. If only a little water enters the detonator, the spit of the burning fuse is often sufficient to cause the fulminating charge to detonate with a sharp report and completely destroy the copper shell. In some of the tests 70 to 80 per cent of the compressed fulminating charge was recovered in the lower part of the copper shell. The spit of the burning fuse had seemingly caused a part of the fulminating composition to detonate, the detonation destroying the top part of the copper shell but not being propagated throughout the remainder of the wet fulminating charge. In these instances a slight report only was audible. Obviously an explosion of this order would not cause a complete detonation of dynamite or other high explosives. In some of the tests a thin coating of tallow was placed on the fuse one-fourth of an inch from the end and extending a distance of one-half of an inch up on the fuse. In the tests in which tallow was placed around the fuse before it was inserted into the detonator a more perfect seal was made.

A new crimper recently placed on the market crimps the detonator on the fuse in a manner different from that of any of the other types of crimpers. The salient feature of this crimper is its ability to contract the top of the detonator uniformly and to form a $\frac{1}{8}$-inch groove around the copper shell, thus perfecting a seal of the detonator on the fuse that will permit submersion under water for 30 minutes. The shell is pressed firmly and uniformly into the fuse, but not far enough to break or separate the powder train. Owing to the varying diameters of different types of fuse and the probability of considerable variation in the same type or even in the same coil of fuse, the use of a thin film of tallow around the end of the fuse that is inserted into the detonator, as described above, will make a better seal irrespective of the crimper used.

TESTS WITH A TRINITROTOLUENE DETONATING FUSE.

As the results of all tests made with explosives sensitive to detonation showed that when a complete detonation was obtained the rate of detonation was practically the same, the authors decided to carry on tests with a few explosives, using No. 6 electric detonators and trinitrotoluene detonating fuse as the initiatory explosive.

The trinitrotoluene detonating fuse used in the tests was a lead tube filled with trinitrotoluene, and is commercially known as "cordeau detonant." The results of physical examination of the fuse were as follows.

Results of physical examination of 6-mm. detonating fuse (cordeau detonant).

Outside diameter, inches	0.2275
Thickness of lead, inches	.0275
Inside diameter of tube, inches	.1725
Weight of a foot length, grams	41.74
Weight of a foot length of lead tube, grams	35.32
Weight of a foot length of charge, grams	6.42
Density of charge	1.40

Consistency of charge: Powdered; very fine; dry; soft; slightly cohesive.
Color of charge: Straw.

The tests were made with explosives in which a 6-inch length of the detonating fuse (cordeau detonant) was embedded centrally at one end of the charge, the side of the fuse being slit and spread open from one end a distance of 1¼ inches. A No. 6 electric detonator was placed against the trinitrotoluene in the slit and tied firmly in place. The electric detonator and attached detonating fuse (cordeau detonant) was imbedded in the explosive. Following is a tabulation of the results of the tests:

Results of rate-of-detonation tests of explosives with a No. 6 electric detonator and detonating fuse (cordeau detonant).

Class of explosive.	Test No.	Rate of detonation.	Average rate of detonation.
		Meters per second.	*Meters per second.*
Class 1, subclass *a* (sample 1)	D981 D982	2,231 2,225	2,228
Class 1, subclass *b* (sample 2)	D990 D991	(*a*) (*a*)	....
20 per cent "straight" nitroglycerin dynamite	D1007 D1008 D1009	3,156 2,947 3,190	3,098
40 per cent strength ammonia dynamite (containing nitrosubstitution compounds)	D880 D883 D884 D885 D886	2,444 (*a*) 2,945 2,821 2,713	2,731
35 per cent strength gelatin dynamite (two years old)	D893 D894	(*a*) (*a*)	....

[a] Incomplete detonation; rate not determined.

Comparative results of tests with detonating fuse fired with No. 6 detonators and with No. 6 electric detonators used alone.

	No. 6 electric detonator and detonating fuse.	No. 6 electric detonator.
Averages of the rate of detonation of three explosives, meters per second	2,686	2,645
Explosive efficiency, per cent	101.6	100.0

The results of the tests show that a 6-inch length of detonating fuse (cordeau detonant) used in connection with a No. 6 electric detonator does not increase the rate of detonation of the explosives

tested. The slight increase indicated in the table is explained by the fact that the rate of detonation of detonating fuse (cordeau detonant) itself is about 4,900 meters per second and that the fuse extended about one-eighth the length of the charge.

If the detonating fuse had extended the full length of the charge the rate of detonation of the explosive would probably have been increased to 4,900 meters per second, the rate of the detonating fuse.

Detonating fuse has been used to some extent in deep-hole blasting. A piece of the fuse is laid beside the charge of high explosive that has been inserted into the hole. The fuse, when detonated, accelerates the rate of detonation of the explosive, thus producing a greater shattering effect on the surrounding rock. Detonating fuse has also been used to replace electric detonators in large blasts when simultaneous blasting is desired. Obviously, when detonating fuse is used in drill holes containing a long charge of explosive whose rate of detonation is less than that of the detonating fuse, a greater shattering effect will be produced. When the rate of detonation of the explosive charge is greater than that of the detonating fuse, the only advantage in using the fuse would be to insure a complete detonation of the entire charge of explosive.

TESTS WITH DETONATORS DISTRIBUTED IN CHARGE.

With long charges of high explosives in blasting work, it has sometimes been the custom to place detonators at intervals in the charges, in the belief that the work accomplished by the explosives would be increased. Rate-of-detonation tests were made with an explosive of class 1, subclass *a*, sample 3 (an ammonium-nitrate explosive containing a sensitizer that is itself an explosive), in charges 1¼ inches in diameter, with and without No. 7 detonators distributed in the explosive, to determine whether detonation of the charge would occur at a greater distance because of the presence of the detonators. The explosive had been previously tested (see p. 29) in charges 1½ inches in diameter, with the result that the No. 7 electric detonator caused complete detonation in every trial, whereas the No. 3 electric detonator failed to do so once out of three trials. The explosive was insensitive to detonation and was purposely chosen for this reason. The results were as follows:

Results of rate-of-detonation tests in which No. 7 detonators were distributed in the charge.

Grade of detonator.	Test No.	Dimensions of galvanized-iron tube used.		Result.
		Diameter.	Length.	
		Inches.	*Inches.*	
No. 7	[a] D1134	1½	42	Detonation incomplete.
No. 7	[b] D1147	1¾	80	Do.
No. 7	[c] D1148	1½	42	Dc.

[a] No detonators distributed in the charge.
[b] Three No. 7 detonators placed every one-half meter in the charge.
[c] Three No. 7 detonators placed every one-fourth meter in the charge.

Further tests were made with an insensitive gelatin dynamite by placing one No. 7 detonator every one-eighth meter in the charge, with results as follows:

Results of rate-of-detonation tests in which No. 7 detonators were distributed in the charge.

Grade of detonator.	Diameter of cartridges.	Dimensions of galvanized-iron tube used.		Length of charge that detonated.
		Diameter.	Length.	
	Inches.	*Inches.*	*Inches.*	*Inches.*
No. 7	1½	1¾	42	21½
No. 7	1½	1¾	42	16
No. 7	1½	1¾	42	20

The results of rate-of-detonation tests with the same explosive, when no extra detonators were used, were as follows:

Results of rate-of-detonation tests without extra detonators.

Grade of detonator.	Diameter of cartridge.	Dimensions of galvanized-iron tube used.		Length of charge that detonated.
		Diameter.	Length.	
	Inches.	*Inches.*	*Inches.*	*Inches.*
No. 7	1½	1¾	42	6
No. 7	1½	1¾	42	15
No. 7	1½	1¾	42	9

The results of the tests tabulated above indicate that extra detonators distributed 5 inches apart in a cartridge file of an insensitive explosive 40 inches long have a slight tendency to increase the propagation of the explosive wave, but that extra detonators placed 10 inches apart offer no advantage.

With an insensitive gelatin dynamite, such as that used in the tests, the influence of the detonator probably does not extend further than 5 inches. Furthermore, the explosion wave and the detonation of the explosive surrounding the detonator probably precede the explosion of the detonator. Assuming this to be true, the detonator is exploded in the products of combustion of the explosive, and, accordingly, offers little, if any, advantage as a means of extending the explosive wave.

Attention is called, however, to the fact that it is often advantageous to fire simultaneously two or more electric detonators placed in different parts of the charge in the same drill hole. Under these conditions, if the charge is fired simultaneously, the time of detonation would be reduced, and, accordingly, the shattering effect of the explosion would be materially increased. Also when long charges of explosives are used, it is sometimes necessary to use more than one electric detonator in the charge to insure complete detonation.

In quarry operations the large drill-hole method of blasting is being rapidly introduced. The former practice of quarrying by the bench method and drilling holes of small diameter, which in many cases requires the chambering of the bottom of the drill holes before loading the main charge, is more expensive.

In some quarries 6-inch holes are drilled 100 feet in depth, and several thousand pounds of explosive is used in a blast. The charges usually extend to a distance of 30 feet up from the bottom of the holes. It has been found that when one electric detonator is placed in the top of the charge it will not always produce a complete detonation of the entire charge in the drill hole; therefore two or more electric detonators distributed throughout the charge are generally used. When the most violent effect is desired in blasting, the best method of placing electric detonators in a charge 30 feet in length, irrespective of whether they are connected in series or parallel, is to place one electric detonator 5 feet from the bottom of the charge, one 5 feet below the top of the charge, and one in the center of the charge. Assuming that the entire charge detonates at a uniform rate, if the three electric detonators are fired simultaneously it can readily be seen that the duration of the explosive reaction will be one-sixth of the time that would be required if one electric detonator were used in the top of the charge.

Tests were made at the bureau's Pittsburgh testing station to determine whether simultaneous explosion would occur when four of the P. T. S. S. No. 6 electric detonators were connected in series and fired with different sources of electric current. In the tests in which a 4-hole firing machine of the dynamo-electric type was used, the time interval that elapsed between the firing of the first and the last electric detonator of each series varied from 0.0004 to 0.0050 second. As it requires only 0.0020 second for 30 feet of 40 per cent "straight" nitroglycerin dynamite to detonate, it is obvious that in many cases the only advantage in using more than one electric detonator in the same charge, when fired with a 4-hole firing machine, would be to insure complete detonation of the charge. It is to be noted that the time interval between the firing of the first and the last electric detonator is in some cases greater than the time required for 30 feet of 40 per cent dynamite to detonate. When a 4-hole firing machine is used to fire four electric detonators connected in series there is not sufficient current generated to fuse the platinum wires in the electric detonators. The wires are brought to different temperatures, depending on their cross-sectional area and, accordingly, the ignition of the priming charge in the electric detonators is not simultaneous, nor is its burning or detonation uniform. These causes are assumed to be responsible for the delay that occurs in the explosion of the electric detonators.

Further tests were made by using a 10-hole firing machine, all other conditions being the same as in the previous tests. The machine furnished ample current to fuse the platinum wires in the electric detonators and they were therefore fired practically simultaneously. The time interval was only 0.0001 second. In order to obtain the benefit of simultaneous blasting when two or more electric detonators are to be fired, the source of electric current should be such as to insure the instantaneous fusing of all the bridges in the electric detonators. This can be best accomplished in practical operations by wiring all electric detonators in parallel and using a light or power circuit for firing. If a high-pressure alternating current is the only source of electricity available, it may be necessary to install a transformer in order to obtain the proper pressure without injury to the leading wires. A lamp bank or a short length of fuse wire is sometimes placed in the electric circuit and answers the same purpose, irrespective of the kind or the pressure of the current supplied. However, if a lamp bank or a fuse wire is used, it should have a greater current-carrying capacity than is necessary to fire all of the electric detonators.

USE OF TWO KINDS OF EXPLOSIVES IN THE SAME DRILL HOLE.

In certain quarry operations in the Middle West, owing to variations in the hardness and structure of the different strata, it is necessary to use more than one kind of explosive in the same drill hole. The part of the drill hole that penetrates the hardest stratum is usually loaded with an explosive having a high rate of detonation. The remainder of the charge may be an explosive having an intermediate rate. In some cases black blasting powder is used, provided there are no pronounced clay seams or other irregularities that would allow the gases evolved on the explosion of the black blasting powder to escape before the main charge detonated. In work of this kind, the holes are drilled vertically 15 to 20 feet deep, and there is always sufficient stemming used to insure the maximum effect of the blast, even when the explosives used in the same drill hole detonate at different rates.

The practice of using combination charges of explosives has been recently adopted in some coal mines. The drill holes are usually shallow and, accordingly, do not permit the use of sufficient stemming properly to confine the gases when they are evolved at different rates. Under such conditions fires and blown-out shots are likely to result.

Several tests made at the Pittsburgh testing station to determine the energy developed by combination charges showed that there was no advantage in using them under conditions that simulated blasting in coal. In some of the tests, a No. 6 detonator (blasting cap) was

inserted in the charge of dynamite, and placed in the back of the bore hole. In front of the detonator a charge of black blasting powder, containing a black powder igniter, was placed, and the free part of the drill hole was then well tamped with clay.

The results of the tests made in the ballistic pendulum, using combination charges of 40 per cent "straight" nitroglycerin dynamite and FFF black blasting powder, with and without a No. 6 detonator embedded in the explosive, were as follows:

The swings of the ballistic pendulum[a] in those tests in which the detonator was used were 3.42, 3.41, 3.40, 3.41, 3.26, 3.32, 3.01, 3.34, and 3.28 inches; average, 3.32 inches. In those tests in which no detonator was used the swings were 3.58, 3.30, 3.32, 3.38, 3.24, 3.31, 3.22, 3.36, and 3.31 inches; average, 3.34 inches.

The tests indicated that there is no advantage in using an extra detonator in the dynamite, as the explosion of the black blasting powder is sufficient to cause complete detonation. Many accidents have occurred in coal mines where combination charges containing detonators were used. When squibs are used for firing, it is necessary to insert a needle into the charge of black blasting powder, and there is always then a possibility of the needle coming in contact with the detonator.

The practice of using combination charges in coal mines offers no advantage, and, as there are many dangers attendant upon their use, the practice should be discouraged.

PUBLICATIONS ON MINE ACCIDENTS AND TESTS OF EXPLOSIVES.

The following Bureau of Mines publications may be obtained free by applying to the Director Bureau of Mines, Washington, D. C.:

Bulletin 10. The Use of Permissible Explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls.

Bulletin 15. Investigations of Explosives Used in Coal Mines, by Clarence Hall, W. O. Snelling, and S. P. Howell, with a chapter on the natural gas used at Pittsburgh, by G. A. Burrell, and an introduction by C. E. Munroe. 1911. 197 pp., 7 pls.

Bulletin 17. A Primer on Explosives for Coal Miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls. Reprint of United States Geological Survey Bulletin 423.

Bulletin 20. The Explosibility of Coal Dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls. Reprint of United States Geological Survey Bulletin 425.

Bulletin 44. First National Mine-Safety Demonstration, Pittsburgh, Pa., October 30 and 31, 1911, by H. M. Wilson and A. H. Fay, with a chapter on the explosion at the experimental mine, by G. S. Rice. 1912. 75 pp., 7 pls.

Bulletin 46. An Investigation of Explosion-Proof Mine Motors, by H. H. Clark. 1912. 44 pp., 6 pls.

Bulletin 48. The Selection of Explosives Used in Engineering and Mining Operations, by Clarence Hall and S. P. Howell. 1913. 50 pp., 3 pls.

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[a] The ballistic pendulum used by the Bureau of Mines is a large mortar swung from a pivoted support. The explosive to be tested is fired from a small cannon into the mouth of the mortar, and the swing of the mortar is taken as a measure of the strength of the explosive.

BULLETIN 52. Ignition of Mine Gases by the Filaments of Incandescent Lamps, by H. H. Clark and L. C. Ilsley. 1913. 31 pp. 6 pls.

TECHNICAL PAPER 4. The Electrical Section of the Bureau of Mines, Its Purpose and Equipment, by H. H. Clark. 1911. 12 pp.

TECHNICAL PAPER 6. .The Rate of Burning of Fuse as Influenced by Temperature and Pressure, by W. O. Snelling and W. C. Cope. 1912. 28 pp.

TECHNICAL PAPER 7. Investigations of Fuse and Miners' Squibs, by Clarence Hall and S. P. Howell. 1912. 19 pp.

TECHNICAL PAPER 11. The Use of Mice and Birds for Detecting Carbon Monoxide After Mine Fires and Explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 12. The Behavior of Nitroglycerin When Heated, by W. O. Snelling and C. G. Storm. 1912. 14 pp., 1 pl.

TECHNICAL PAPER 13. Gas Analysis as an Aid in Fighting Mine Fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp.

TECHNICAL PAPER 14. Apparatus for Gas-Analysis Laboratories at Coal Mines, by G. A. Burrell. 1913. 24 pp., 7 figs.

TECHNICAL PAPER 17. The Effect of Stemming on the Efficiency of Explosives, by W. O. Snelling and Clarence Hall. 1912. 20 pp.

TECHNICAL PAPER 18. Magazines and Thaw Houses for Explosives, by Clarence Hall and S. P. Howell. 1912. 34 pp., 1 pl.

TECHNICAL PAPER 19. The Factor of Safety in Mine Electrical Installations, by H. H. Clark. 1912. 14 pp.

TECHNICAL PAPER 21. The Prevention of Mine Explosions; Report and Recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369.

TECHNICAL PAPER 22. Electrical Symbols for Mine Maps, by H. H. Clark. 1912. 11 pp., 8 figs.

TECHNICAL PAPER 23. Ignition of Mine Gas by Miniature Electric Lamps, by H. H. Clark. 1912. 5 pp.

TECHNICAL PAPER 24. Mine Fires, a Preliminary Study, by G. S. Rice. 1912. 51 pp.

TECHNICAL PAPER 28. Ignition of Mine Gas by Standard Incandescent Lamps, by H. H. Clark. 1912. 6 pp.

TECHNICAL PAPER 40. Metal-Mine Accidents in the United States during the Calendar Year 1911, by A. H. Fay. 1913. 54 pp.

TECHNICAL PAPER 46. Quarry Accidents in the United States during the Calendar Year 1911, compiled by A. H. Fay. 1913. 32 pp.

TECHNICAL PAPER 48. Coal-Mine Accidents in the United States, 1896–1912, with Monthly Statistics for 1912, by F. W. Horton. 1913. 72 pp.

TECHNICAL PAPER 53. Proposed Regulations for the Drilling of Gas and Oil Wells, with Comment thereon, by O. P. Hood and A. G. Haggem. 1913. 28 pp., 2 figs.

MINERS' CIRCULAR 3. Coal-Dust Explosions, by G. S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The Use and Care of Mine-Rescue Breathing Apparatus, by J. W. Paul. 1911. 24 pp.

MINERS' CIRCULAR 5. Electrical Accidents in Mines; Their Causes and Prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1911. 10 pp., 3 pls.

MINERS' CIRCULAR 6. Permissible Explosives Tested Prior to January 1, 1912, and Precautions to be Taken in Their Use, by Clarence Hall. 1912. 20 pp.

MINERS' CIRCULAR 9. Accidents from Falls of Roof and Coal, by G. S. Rice. 1912. 16 pp.

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